Environment Canada | Environnement Canada
Conservation and Protection | Conservation et Protection

RESEARCH AND INFORMATION NEEDS FOR CANADIAN WETLANDS

Proceedings of a Workshop on Wetland Hydrogeochemistry

BESOINS EN MATIÈRE DE RECHERCHE ET D'INFORMATION SUR LES TERRES HUMIDES AU CANADA

Compte rendu d'un atelier sur l'hydrogéochimie des terres humides

Environment Canada Environnement
Canada. Inland Waters Directorate. Technical workshop series
Nov 10 Date: 1991
TD 149 C3b 00274440
DOEE Exc 1

TECHNICAL WORKSHOP SERIES NO. 10

ÉTUDE N° 10, SÉRIE DES ATELIERS TECHNIQUES

INLAND WATERS DIRECTORATE
OTTAWA, CANADA, 1991

DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES
OTTAWA, CANADA, 1991

Canada

RESEARCH AND INFORMATION NEEDS FOR CANADIAN WETLANDS

Proceedings of a Workshop on Wetland Hydrogeochemistry

BESOINS EN MATIÈRE DE RECHERCHE ET D'INFORMATION SUR LES TERRES HUMIDES AU CANADA

Compte rendu d'un atelier sur l'hydrogéochimie des terres humides

Prepared for/Préparé pour

Environment Canada/Environnement Canada

by/par

Christopher H.R. Wedeles
J. Donald Meisner
Michael J. Rose

ESSA Environmental and Social Analysts Ltd.
Suite 308, 9555 Yonge Street
Richmond Hill, Ontario, L4C 9M5

TECHNICAL WORKSHOP SERIES NO. 10

ÉTUDE N° 10, SÉRIE DES ATELIERS TECHNIQUES

INLAND WATERS DIRECTORATE
OTTAWA, CANADA, 1991

DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES
OTTAWA, CANADA, 1991

92-01705/

Printed on paper that contains recovered waste

Cover photo: Canadian Wildlife Service

Table of Contents

Foreword v

Executive Summary vi

Résumé viii

Acknowledgements x

1.0 Introduction 1

2.0 Information and Research Needs Relating to Natural Hydrogeochemical Processes .. 3
2.1 Geochemical Processes 3
2.1.1 Carbon and Nutrient Cycling, Exchange, and Storage 3
2.1.2 Metal Mobilization 4
2.2 Hydrological and Hydrometeorological Processes 5
2.2.1 Internal Hydrological Dynamics 5
2.2.2 Hydrological Links with External Systems 6
2.3 Ecosystem Interactions 7
2.3.1 Linkages Between Geochemistry and Hydrology 7
2.3.2 Wetland Evolution and Ecosystem Dynamics 8

3.0 Information and Research Needs Related to the Effects of Human Activity 9
3.1 Global Climate Change 9
3.2 Atmospheric Pollution 11
3.3 Land Use 13
3.3.1 Land Use Activities 13

4.0 Information and Research Needs Relating to Wetland Habitat 17
4.1 Ecological Dynamics 17
4.1.1 The Carbon, Nitrogen, Phosphorus and Sulphur Cycles 17
4.1.2 Population Dynamics of Plant and Animals 18
4.1.3 Wildlife Response to Alterations in Hydrology and to Other Changes in Habitat 19
4.2 Limiting Factors Affecting the Distribution of Organisms 19
4.2.1 Precipitation and Temperature 19
4.2.2 Nutrients 20
4.2.3 Acid/Base Balance and Salinity 20
4.2.4 Hydrology 20
4.2.5 Species Interactions and Wetland Size 21

4.3 Wetland Interactions with Other Habitats 21
4.3.1 Natural Habitats 22
4.3.2 Human Induced Drainage Alterations 23
4.3.3 Human Induced Habitat Alteration and Land Use Change 23
4.3.4 Atmospheric and Stream Deposition 23

4.4 Wetland Restoration/Preservation 23
4.4.1 Wetland Succession 24
4.4.2 Wetland Restoration 24

5.0 Recommendations 27
5.1 Infrastructural and Organizational Recommendations 27
5.2 Inventory and Monitoring 28

6.0 References 31

Appendix 1: List of Workshop Participants 35

Appendix 2: Abstracts of Papers Presented at the Symposium 37

List of Papers:

1. Wetlands and Water Quality Concerns
2. Hydrology of Peatlands
3. Northern Wetland Study (NOWES)
4. Hydrology of Prairie Wetlands
5. Hydrological-Geochemical Interactions in Wetlands
6. Geochemistry of Peat and Water Table of Peatlands in West-Central Canada
7. Extended Abstract "Humic Lake Acidification Experiment (HUMEX")
8. Wetlands and Sensitivity of Terrestrial Carbon Cycle on Atmospheric Carbon Dioxide
9. Methane Emissions from Peatlands
10. Suggestions as to Wetlands Research Needs

Foreword

This workshop was conceived with four sometimes incompatible objectives in mind. The first was to inform science managers of what workers felt were the most pressing wetland research and monitoring needs to be filled. Secondly, we attempted for the benefit of scientists, to summarize state of the art information regarding various aspects of wetlands science.

Third, we prepared a series of recommendations which should be used by scientists attempting to orient new or existing studies. Finally, we felt that we needed to propose some organizational initiatives to facilitate the imposing task of understanding wetlands.

I think that most of these objectives were achieved due to the effort put in by the Workshop participants and the consultants. Once more, the organizing committee thanks those who made the meeting so successful.

Thomas Clair
Chairman

Executive Summary

Environment Canada is presently reviewing the way it studies wetlands. In order to help in this task, a symposium and workshop on the hydrogeochemistry of wetlands was held at the Canada Centre for Inland Waters, Burlington, Ontario, March 19-21, 1991. Wetland scientists were brought together to: 1) review recent advances in wetlands science; and 2) identify research and information needs that Environment Canada must respond to in coming years. The symposium consisted of a series of formal presentations by the scientists. Abstracts of these papers are found in Appendix 2 of this report. Following the symposium, workshops were convened in which participants of the symposium worked together to identify research and information needs for wetlands.

The purpose of this document is to report on the research and information needs for wetlands that were identified in the workshops. Key knowledge and information gaps regarding physical and chemical aspects of Canadian wetlands were identified under three broad categories: natural hydrogeochemical processes; effects of human activity; and wetlands as habitat.

Some of the specific needs to increase understanding of the natural hydrogeochemical processes of wetlands were identified as:

- carbon and nutrient cycling, exchange and storage;
- the role of metal mobilization;
- internal wetland hydrological dynamics and hydrological links with external systems; and
- wetland evolution and ecosystem dynamics.

More basic research in this area is crucial to developing knowledge of the effects of perturbations on wetlands.

Information and research needs related to the effects of global climate change, atmospheric pollution, and land use activities were identified. Some important research needs in order to better understand the effects of these human-induced perturbations on wetlands are:

- role of water table in wetland function and integrity;
- interaction of temperature and moisture in the wetland soils;
- nitrogen dynamics in wetlands;
- influence of acidic precipitation;
- long-term response of wetlands to agricultural practices; and
- efficacy of "no net loss" conservation policies.

The knowledge gaps relating to wetlands as habitat were both diverse and numerous. Broadly grouped, they included acquiring a better understanding of:

- wildlife responses to wetlands change;
- the limiting factors of precipitation, temperature, and water quality on the distribution of organisms;
- interactions between differing habitats, both natural and altered;
- consequences for wetlands of atmospheric and stream deposition; and
- wetland succession and wetland restoration.

In order to effectively address these knowledge gaps, integrated inter-institutional wetland research is needed. Similarly, management approaches must also be integrated. To this end, workshop participants developed recommendations relating to the infrastructural and organizational requirements for such research. Recommendations for inventory and monitoring mechanisms were also provided. The recommendations are as follows:

- developing a national policy for protecting wetlands;
- establishing a body to coordinate national wetlands research;
- developing wetland centres of excellence;
- establishing a subvention grant program for wetlands research;
- integrating existing data into comprehensive databases and inventories;
- developing well-designed monitoring programs; and
- developing ecological and jurisdictional integration of classification systems.

Résumé

Environnement Canada examine la façon dont il étudie les terres humides. Pour faciliter l'examen, un symposium et un atelier sur l'hydrogéochimie des terres humides ont eu lieu au Centre canadien des eaux intérieures de Burlington, en Ontario, du 19 au 21 mars 1991. L'événement a réuni des spécialistes des terres humides venus examiner les derniers progrès de la science au chapitre des terres humides et cerner les besoins en matière de recherche et d'information auxquels Environnement Canada doit répondre dans les années à venir. Le symposium comprenait une série d'exposés formels donnés par les scientifiques; on en trouvera les résumés à l'annexe 2 du présent compte rendu. Par la suite, les participants au symposium ont été invités à se regrouper afin de déterminer ensemble les recherches à effectuer et les données à obtenir relativement aux terres humides.

Le présent document vise à faire rapport au sujet des besoins en recherche et en information sur les terres humides qui ont été identifiés lors de l'atelier. Les principales lacunes identifiées relativement aux connaissances et aux renseignements concernant les aspects physiques et chimiques des terres humides au Canada ont été classées en trois grandes catégories : les processus hydrogéochimiques naturels; les effets de l'activité de l'homme; les terres humides en tant qu'habitat.

Parmi les besoins précis exprimés en vue d'accroître la compréhension des processus hydrogéochimiques naturels des terres humides, citons :

- le cycle du carbone et des éléments nutritifs ainsi que les échanges et le stockage;
- le rôle de la mobilisation des métaux
- la dynamique hydrologique interne des terres humides et leur liens hydrologiques avec des systèmes externes;
- l'évolution des terres humides et la dynamique des écosystèmes.

Il est primordial d'accroître la recherche fondamentale dans ce domaine afin d'acquérir des connaissances à propos des effets qu'ont les perturbations sur les terres humides.

Les conséquences du changement climatique planétaire, la pollution atmosphérique et l'utilisation des terres constituent des perturbations anthropiques pour lesquelles des besoins en recherche et en information ont été identifiés. Afin de mieux comprendre les effets de ces perturbations sur les terres humides, les participants ont convenu qu'il fallait effectuer de la recherche sur :

- le rôle de la surface de saturation sur la fonction et l'intégrité des terres humides;
- l'interaction de la température et de l'humidité dans les sols des terres humides;
- la dynamique de l'azote dans les terres humides;
- l'influence des précipitations acides;
- les conséquences à long terme des procédés agricoles sur les terres humides;
- l'efficacité de la politique de conservation qui vise aucune perte nette des terres humides.

Les lacunes au plan des connaissances sur les terres humides en tant qu'habitat sont à la fois diverses et nombreuses. Si on les regroupe sommairement, elles comprennent l'acquisition de mielleures connaissances sur :

- les réactions de la faune aux changements apportés aux terres humides;
- les facteurs limitatifs des précipitations, de la température et de la qualité de l'eau sur la répartition des organismes;
- les interactions des différents habitats, tant naturels que modifiés;
- les conséquences sur les terres humides des dépôts dans l'air et les cours d'eau;
- la succession et la restauration des terres humides.

Dans le but de combler adéquatement ces lacunes, il faut effectuer de la recherche intégrée regroupant plusieurs organismes et portant sur les terres humides. De même, les méthodes de gestion doivent aussi être intégrées. À cette fin, les participants ont formulé des recommandations en ce qui concerne l'infrastructure et l'organisation requises pour mener à bien cette recherche. Ils ont en outre présenté d'autres recommandations sur les mécanismes nécessaires en matière d'inventaire et de surveillance, soit :

- élaborer une politique nationale de protection des terres humides;
- mettre sur pied un groupe chargé de coordonner la recherche effectuée à l'échelle nationale sur les terres humides;
- établir des centres d'excellence sur les terres humides;
- créer un programme de subventions à la recherche sur les terres humides;
- voir à l'intégration des données présentement disponibles dans des bases de données et des inventaires exhaustifs;
- créer des programmes de surveillance bien conçus;
- intégrer divers systèmes de classification qui ont des limites soit écologiques ou politiques.

Acknowledgements

We thank all the workshop participants for their energy and enthusiasm throughout the workshops. Their insight and ideas form the basis of this report.

The workshop would not have been possible without the financial and moral support of a number of groups. These include: Inland Waters Directorate, Atlantic Region and Headquarters (Mr. Steve Fenety and Mr. Robert Hélie); the National Hydrology and National Water Institutes (Dr. Ralph Daley and Dr. Milne Dick); the Inland Water Directorate LRTAP scientific coordinator (Dr. Dean Jeffries); the Environmental Integration Service and Air Quality and Environmental Research Branches of the Atmospheric Environment Service (Mr. Tom Brydges, Dr. Hans Martin and Dr. Ann MacMillan); the Canadian Wildlife Service Headquarters (Mr. Gerry Lee); and the Northern Wetlands Project (Dr. Walter Glooschenko). The organizing committee was composed of Thomas Clair (Chairman), Walter Glooschenko, Rick Langford, Wally Nicholaichuk and Clayton Rubec.

Thanks to Tamara Lekstrum and Kimberly Pawley for editing this report, and to Gwen Eisler and Jill Kell for assistance in preparing earlier drafts.

1.0 Introduction

In spite of the fact that wetlands occupy much of Canada (approximately 14%), we know relatively little about them. Historically, wetlands have been perceived as wastelands to be drained and/or filled to accommodate urban expansion, agriculture and forestry. We now know however, that wetlands play crucial physical and chemical roles which profoundly influence the health and functioning of ecosystems. If wetlands are to be preserved for the future, their management must be based upon a sound understanding of their function and interaction with the environment, and of the benefits they provide for environmental maintenance, humans, and wildlife.

Environment Canada recognizes the need to explicitly identify the key knowledge and information gaps regarding the physical and chemical aspects of Canadian wetlands. To this end Environment Canada hosted a symposium and workshop on wetland hydrogeochemistry, held in Burlington, Ontario on March 19-21, 1991. The symposium consisted of a formal review of recent advances in wetland science. Following the symposium, the participants met in workshops to identify wetland research and information needs. The purpose of this report is to present the wetland information needs that were identified in the workshop, with the hope that doing so will provide impetus toward resolving them.

There is considerable scientific and public interest in the effects of broad-scale anthropogenic perturbations (e.g. climate change and acid rain) on wetlands, and the role that wetlands may play in ameliorating the effects of these stresses on the biosphere. An attempt to fully comprehend these effects must be based on an understanding of the natural dynamics of wetlands. This rationale has partially dictated the structure of this report. Section 2.0 examines the information needs as they relate to fundamental wetland hydrogeochemical processes. Naturally, the depth of our understanding of these processes will limit our level of understanding of the effects of anthropogenic perturbations. Section 3.0 examines the information needs that are more directly related to the effects of human-induced perturbations. There is considerable overlap between Sections 2.0 and 3.0, however they are kept separate in this report to emphasize the need to base our understanding of perturbations on an understanding of natural dynamics.

Many people consider the most important function of wetlands to be the provision of wildlife habitat. Section 4.0 of this report examines the information and research needs associated with this function.

The recommendations that emerged from the workshop are presented in Section 5.0. Many of the recommendations are intended to address more than one of the information needs identified in Sections 2.0 - 4.0. In general, each of the recommendations that emerged from the workshop discussions relates to one of two types of activities:

- developing infrastructural and organizational services and capabilities; and
- developing inventory, monitoring and research tools and mechanisms.

Although these categories of activities are not entirely discrete, they do form a useful framework for discussing the recommendations.

The information needs identified in this report are, by necessity, broad in scope. We recognize that by identifying broad needs there is a danger that some specific needs may "fall between the cracks". It is not the intention of this report, however, to identify all important research and information needs related to wetlands, but rather to identify some of the pressing information needs and to draw attention to the necessity of making progress towards resolving these needs given the important role that wetlands play in Canada's ecosystems.

2.0 Information and Research Needs Relating to Natural Hydrogeochemical Processes

We have discussed research and information needs under the following fundamental wetland processes:

1. Geochemical Processes
   - carbon and nutrient cycling, exchange and storage
   - metal mobilization

2. Hydrological and Hydrometeorological Processes
   - internal hydrological dynamics
   - dynamic hydrological links with external systems

3. Ecosystem Interactions
   - linkages between geochemistry and hydrology
   - wetland conversion and ecosystem dynamics

There is considerable overlap between these categories. Our intent in using them is not to suggest that all concerns can be conveniently categorized into one or the other, but merely to provide a structure for discussion.

2.1 Geochemical Processes

2.1.1 Carbon and Nutrient Cycling, Exchange, and Storage

Nutrient cycling in essence defines the biological productivity of wetlands. Because the availability of nutrients greatly influences the suitability of wetland habitats for plants and animals, an understanding of nutrient cycling will improve our understanding of the biological value and function of wetlands.

In this discussion we placed particular emphasis on carbon cycling because of the significant role that carbon compounds play, through trace-gas chemistry, in influencing the global carbon cycle. This aspect of wetlands is also one of the foci of the investigations of the Canadian Northern Wetlands Study (Mortsch 1990, Schiff and Barrie 1988).

Specific information needs related to element cycling in wetlands include:

1. ***The size and source of the carbon sink in peatlands:*** The role of the natural sources and sinks of carbon gases and compounds is not well understood. Peatlands are known to produce and store both carbon dioxide and methane (CO_2 and CH_4) (Mortsch 1990). Both are significant "greenhouse gases",

however the amounts of each contained in peatlands is not known. This is a very significant information gap because Canada's peatlands make up a significant portion of the earth's total.

2. ***The rates of accumulation of carbon and organic material in peat:*** To understand the role of peatlands in the natural environment, it is important not only to quantify the amount of carbon compounds peatlands contain, but also to develop an understanding of the mechanisms and rates of their accumulation.

3. ***The processes involved in nitrogen, phosphorus, and sulphur cycles in wetlands:*** Similar to items #1 and #2 above, nutrient cycling both controls and is part of the wetland biological processes. It is critical to develop an understanding of such cycling before we can fully comprehend the role that wetlands play in the environment. This need is especially pronounced in the southern freshwater wetlands and northern peatlands.

4. ***The role that organic materials play in the production and storage of carbon, nitrogen, phosphorus, and sulphur:*** This item is clearly a component of those items listed above, but is mentioned separately because of the vast amounts of organic material stored in wetlands.

2.1.2 Metal Mobilization

Although it is known that wetlands can play a major role in sequestering metals or releasing them into surface waters, the variety of processes which together substantially alter the chemistry of waters moving through wetlands is not well understood. In recent years the acid precipitation problem has stimulated substantial advances in this area, but our understanding of these processes remains primarily descriptive rather than predictive.

Specific information needs identified at the workshop relate to:

1. ***The role that wetlands play in the mobilization of trace metals:*** Because of the relative toxicity of some metals (and their potential impact on ecosystem health), it is important to develop an understanding of the role that wetlands play in the dynamics of metal movement through the environment.

2. ***The role that wetlands play in "buffering" contaminants:*** This information need is clearly related to #1 above, but emphasizes a different aspect of the process. Although wetlands are thought to have value for their ability to retain some metals for long periods, there is conflicting evidence as to whether this is an accurate assessment of the potential of some wetlands (Jones et al. 1986).

3. ***The effects of pH on the mobility of organically bound harmful metals:*** The chemistry of organically complex metals in wetlands is complicated. Low pH is known to affect the mobility of some metals but the relationship is difficult to quantify.

2.2 Hydrological and Hydrometeorological Processes

2.2.1 Internal Hydrological Dynamics

We were concerned largely with gaining a better understanding of the frequency and magnitude of water storage changes in wetlands. It is well known that wetlands act as runoff source areas under wet conditions and as storage areas and runoff attenuators under drier conditions (Woo and Valverde 1981; Taylor and Pierson 1984; both cited in Jones et al. 1986). Many important uncertainties exist, however, about the temporal and spatial dynamics of water storage in wetlands.

Specific information needs identified at the workshop relate to:

1. ***Water storage ability of peatlands:*** All wetlands, not just peatlands, can play a central role in water storage within the watersheds containing them. In fact, their importance is often disproportionately greater than their size relative to the total catchment area. This is an important research need because peatlands make up such a large proportion of Canada's total wetlands, and because the importance of quantifying the water storage ability of wetlands is most marked for peatlands.

2. ***The role of permafrost in influencing flow regimes:*** Because permafrost restricts the vertical flow of water, the capacity of northern wetlands to attenuate flood peaks and sustain baseflow during dry periods is probably limited. However, the precise role of permafrost in influencing flow regimes is not well understood.

3. ***Seasonal water table changes in wetlands, particularly in small catchments:*** Although we know that, in general, wetlands hold water during times of high flow and release it during times of low flow, a better understanding of this role is needed. This is particularly important for small catchments because these systems are the most likely to be hydrologically affected by wetlands.

4. ***Effects of episodic water table changes in wetlands:*** The response of wetlands to episodic inputs of water is not well understood. How rapidly different types of wetlands respond to storm and drought events requires investigation.

5. ***Effects of water table changes on wetland type:*** Major wetland types are distinguished by the extent to which they interact with groundwater; the swamp-bog continuum is largely determined by exposure to groundwater. Aside from general ecological relationships, specific information is required about the influence of the water table on wetland gas dynamics, productivity, decomposition rates, and water retention properties.

6. ***Hydrologic information on a regional scale:*** There is a serious shortage of good hydrological information (e.g. hydrometric data) on a regional scale, particularly for small catchments. This information need is directly related to those mentioned earlier, but has other implications as well because these systems are most likely to be hydrologically affected by wetlands.

2.2.2 Hydrological Links with External Systems

Wetlands are hydrologically linked to the atmosphere and to terrestrial and aquatic ecosystems. Our discussion centred on the information needs associated with these linkages. Specific information needs include:

1. ***Identification of wetlands which have valuable hydrologic functions:*** Wetlands with significant hydrologic value need to be identified in an integrated manner throughout Canada (some regional efforts have been made). Given that this is a potentially important aspect of wetlands which should be considered in their management, it is critical to resolve this information need.

2. ***Groundwater-surface water linkages:*** This information need overlaps with several of those discussed in Section 2.1. More information is needed on the dynamics of the hydrological linkages between the different wetland types and ground water. This will enable us to better understand the role of wetlands in influencing groundwater, and how to manage the former in light of this role.

3. ***Vertical transport of water in peatlands:*** This information need is a component of the previous one, but bears independent mention because of its significance. The unsaturated zone (acrotelm) of a wetland is the upper and most active layer and is the most interactive with the atmosphere. As a result of the interactions with the atmosphere, relatively large fluctuations in temperature and moisture occur. The temperature and moisture regimes of the acrotelm are interdependent, and both greatly influence the water table. They also influence the rates of peat production and decomposition. In turn, peat production and decomposition greatly influence the type and successional trajectory of wetlands. Thus, an improved understanding of the energy budget of the acrotelm, which is driven by temperature and moisture, would contribute to knowledge of the role of the water table.

4. ***The role of evapotranspiration in influencing water budget:*** Evapotranspiration is the most poorly understood element of the wetland's water budget. A better understanding of the role of evapotranspiration is needed before an adequate understanding of wetland hydrology can be achieved.

5. ***The role of the plant community in evapotranspiration:*** It is well known that large quantities of water are transpired by plants during photosynthesis. However, the precise role that plant transpiration plays in influencing the water budget of wetlands is not well understood.

6. ***Recharge and discharge dynamics of wetlands as influenced by landscape features:*** Local topography can greatly influence the recharge and discharge dynamics of wetlands. For example, isolated, perched wetlands can respond quite differently during low flow periods than low-lying wetlands (Boelter and Verry 1977, cited in Jones et al. 1986). However, the influence of topography on wetland hydrology is largely unknown, particularly on a regional scale. This information need is related to several of those discussed in the previous section.

2.3 Ecosystem Interactions

Our discussion of ecosystem interactions focused on the information needs associated with:

- the linkages between geochemistry and hydrology; and
- the temporal changes, or evolution of wetlands in the context of the broad terrestrial ecosystems of which they are a part.

2.3.1 Linkages Between Geochemistry and Hydrology

Few geochemical processes in wetlands, including those discussed in Section 2.1, operate in isolation from hydrological processes. Similarly, few hydrological processes are uninfluenced by geochemical mechanisms. The extent to which these processes are interdependent is really a matter of degree rather than absolutes. The information needs identified here are those which we believe are relatively more based on linkages between geochemistry and hydrology than the information needs discussed in earlier sections. Specific information needs on the linkages between geochemistry and hydrology include:

1. ***The response of water quality to changes in water quantity:*** Intuitively it is simple to see how the general quality of water in a wetland is related to its volume of standing and flowing water. Quantitative relationships, however, are not simple. Of particular interest is the impact of water volume changes on the concentrations of metals, dissolved organic carbon, and wetland nutrients.

2. ***The role of hydrology in retention of organics and metals:*** (This is likely a component of # 1.) As mentioned earlier, the various processes that together substantially alter the chemistry of waters moving through wetlands are not well understood. Although there is a reasonable amount of evidence to support the contention that its role is a qualitatively important one (Jones et al. 1986), at present, no direct evidence exists that can be used to quantify the role of hydrology in wetland chemistry.

3. ***Peatland energy-permafrost relationships:*** Permafrost underlies much of Canada's northern peatlands. The relationship between climate and peatland permafrost is, at best, understood only in qualitative terms.

4. ***Wetland inputs of DOC in basin chemistry:*** Wetlands are important sources of organics for other surface waters (Gorham et al. 1986). Attempts to predict DOC concentrations in surface waters from the amount of wetland in catchments have, however, yielded mixed results (Kessel-Taylor 1985, cited in Jones et al. 1986). This suggests our knowledge of wetland sources of DOC is incomplete. Little is known about the relative contributions of DOC from different wetland types.

2.3.2 Wetland Evolution and Ecosystem Dynamics

Compared to most of the needs listed above, the needs documented below are broad in nature. Each need has many components which could be research studies in themselves. Resolving these broad needs will only be achieved through extensive integrated research efforts. The research needs identified related to:

1. ***Role of wetlands in long-term ecosystem dynamics:*** The long-term evolution of ecosystems is shaped by allogenic (outside) forces such as geological and climate changes and autogenic (inside) forces resulting from activities of the living ecosystem components. Much remains unknown about how wetlands change over long periods of time and how they influence changes in terrestrial and aquatic ecosystems.

2. ***Wetland dynamics in the context of terrestrial and aquatic ecosystems:*** This need centres on the relationship of wetlands to the surrounding ecosystems (similar to #1 above) but is cast in the context of present relationships rather than long-term change.

3.0 Information and Research Needs Related to the Effects of Human Activity

Canada's wetlands are disappearing at an alarming rate due to human activities (Rubec 1991). Wetlands are altered through drainage and/or infilling, in order to accommodate agriculture, forestry and urban expansion. Over the last two decades, concerns that air pollution and climate change are also contributing to wetland loss have been raised by both the public and private sectors.

In this section we have identified the information needs related to geochemical and hydrological process which must be met so as to better understand the effects of human activities on wetlands. Such information is essential for developing effective mitigation measures. The information needs defined at the workshop fall into the three categories listed below.

- global climate change;
- atmospheric pollution; and
- land use.

3.1 Global Climate Change

Over the next century, the increasing concentrations of radiatively active gases (e.g. CO_2 and CH_4) in the lower atmosphere are expected to alter air temperatures and precipitation patterns in North America (Bolin et al. 1986, Jaeger 1988). In central Canada, for example, summers are expected to become drier and warmer, while winters become wetter (Kellog and Zhao 1988). It is difficult to predict and mitigate the potential effects of climatic change on Canada's wetlands because the influence of seasonal and annual climate on wetland structure and function is not well understood.

The climate variables of interest (with respect to the effects of climatic change on wetlands) are air temperature, precipitation, atmospheric CO_2, atmospheric ozone and UV-B. The research that is needed in order to better understand the effects of climate change on the geochemical and hydrological aspects of wetlands is listed below.

1. ***The effects of water table fluctuations on wetland function and integrity:*** The water table is the single most important variable governing the function and distribution of wetlands. The degree of contact with the water table determines the wetland type and the wetland's control on local basin hydrology and its effect on water quality.

   The projected changes in seasonal and annual air temperatures ($\approx$ + 4.0 C° in an atmosphere with doubled CO_2) and changes in regional precipitation will affect regional water tables, and consequently, the availability of groundwater to wetlands. Empirical data show that water table depth follows mean annual precipitation (Regier and Meisner 1990). Clearly then, a sound understanding

of the role the water table plays in controlling wetlands is important with respect to climate change. Studies are needed to elucidate the influence of the water table on wetland gas dynamics, productivity, decomposition rates, and water retention properties of wetlands.

2. ***The interaction of temperature and moisture in the unsaturated zone (acrotelm) of wetlands:*** (This was discussed in detail in Section 2.2.2, #3) An improved understanding of the temperature-moisture interactions of the acrotelm (i.e. the energy budget) would contribute to the knowledge of the water table's role in wetland function. Obviously, improved knowledge in this area is important to an understanding of wetland response to climate change.

3. ***The effect of changes in the quantity of water in, or flowing through, a wetland on wetland water quality:*** Intuitively, the quality of water in a wetland should be affected by a change in its volume of standing water, or by a change in its throughflow. Research is needed to better understand the relationships between water quantity and water quality of wetlands and the sensitivity of different wetland types to hydrology-mediated changes in water quality. Of particular interest is the effect of changes in water volume on the concentration of metals, dissolved organic carbon (DOC), and nutrients. Another area where research is needed consists of determining the importance of aeration on the rooting zone.

4. ***Effects of permafrost melting:*** The projected increases in surface temperatures in a "warmer" climate are expected to be greatest at high latitudes due to the positive feedback effect of reduced albedo (Bolin et al. 1986). Since groundwater temperature tracks mean annual air temperature (Meisner et al. 1988), a warmer climate would likely cause significant reductions in permafrost. The effect of released frozen groundwater on wetlands and local hydrology is not well understood (e.g. will new wetlands be created, existing wetlands enlarged, or will thermokarst erosion cause the released groundwater to run off the land, resulting in a net loss of moisture?) Concomitant with changes in permafrost are potential changes to the local hydrological regime. The potential effects of large scale changes in permafrost due to climate change need to be further investigated.

   Another potential effect of permafrost melting warrants investigation. Some permafrost contain crystals of water and methane called clathrates (MacDonald 1989). The quantity of methane in these crystals is estimated to be in gigatons. Its release into the atmosphere would provide a positive feedback effect to the "greenhouse effect" and could in turn affect wetlands due to the important role of methane in wetland dynamics (Moore 1991).

5. ***Influence of atmospheric CO_2 , temperature, and moisture on growth:*** The projected changes in regional air temperatures and precipitation patterns in response to doubled atmospheric CO_2 is expected to affect the growth, and

ultimately, the distribution of wetlands. While air temperature, precipitation, and atmospheric CO_2 are believed to play a key role in wetland growth and productivity, the mechanisms through which these variables interact with wetlands are not well understood. In addition to influencing basin water quality and hydrology, wetlands also provide important habitat for terrestrial and aquatic wildlife (Prince and D'Itri 1985). Changes in wetland growth and production in response to climate change will undoubtedly affect the wildlife populations that are dependent upon them for habitat. Research is needed to identify the mechanisms by which these variables elicit control on wetland growth, distribution, and dependent wildlife.

6. ***Response to changes in fire frequency and intensity:*** Regional changes in precipitation and seasonal air temperatures (due to climate change), are expected to significantly increase the frequency and magnitude of forest and grassland fires in the boreal forest zone of Canada (Harrington 1989). Relatively little is known of the role natural burn-overs play in wetland function. Do wetlands require these periodic reset events? Are different wetland types equally tolerant of changes in fire frequency? More research on the role of fire in wetlands is needed in order to better understand and prepare for climate change. Studies of the response of Canadian wetlands to past fire regimes would provide insight into the sensitivity of wetlands to fire.

7. ***Adaptiveness of wetlands to climatic change:*** Wetlands, like other ecological systems, have evolved in a dynamic physical environment. The current belief is that wetlands, especially shoreline wetlands, depend on relatively large seasonal fluctuations in water availability and temperature to maintain their inherent structural diversity (Keddy and Reznicek 1986). The regional distributions of wetlands are also thought to be governed by climate, but it is difficult to predict how climate change will impact wetlands. Different types of wetlands (i.e. bogs and fens) will likely respond differently and/or vary in their sensitivity to permanent and large-scale temperature and moisture changes. One important information gap which exists concerns the effects of climate change, for each locale, on the natural successional trajectory of fen to bog. Will climate change be too fast to ensure ecosystem integrity?

3.2 Atmospheric Pollution

The local and long range transport of air pollutants is one component of global environmental change that is believed to be affecting Canadian wetlands. Of particular concern is the deposition of sulphur and nitrogen oxides, metals, and organic contaminants such as insecticides. Specific concerns associated with atmospheric pollution are described by the following research needs.

1. ***Effects of nitrogen deposition on the retention and release of nitrogen by wetlands:*** Little is known about the effects of increased concentrations of atmospheric nitrogen on wetlands. Of particular interest are the potential effects of nitrogen on the acidification and eutrophication of wetlands. Because nitrogen is one of the primary limiting nutrients for plant growth, the implications of the anthropogenic increase in its availability to wetlands flora requires investigation.

2. ***Long-term fate of sulphate, metals, and organic compounds in wetlands:*** Wetlands act as sinks for air-borne metals and organic substances. However, the fate and effects of deposited sulphate, associated hydrogen ions, metals, and organics on different wetland types is not well understood. The interaction of these substances with DOC of wetlands also requires investigation. For example, pulsed releases of sulphur in the spring or after heavy precipitation events are believed to contribute to episodic depressions of pH in downstream surface waters. These local acidification events are, in turn, suspected to affect DOC and metals in wetlands.

   Many issues need to be addressed in order to better understand the effects of long range transport of air pollutants on wetlands. For example, what is the role of the solid phase (peat) in retaining such pollutants by absorption or complexion? Does DOC enhance discharge of these substances from wetlands? Is the quality of DOC of wetlands being altered due to the influx of these pollutants?

3. ***The effect of wetland hydrology on the storage of air-borne pollutants:*** In addition to studying the effects of air transported metals and organic compounds on wetlands, research is needed elucidate the effects of wetland hydrology on the fate of these substances. It is not well understood how the hydrology of different wetland types affects the activity and retention of these pollutants. More research is needed to determine the role of wetlands in regulating the retention and release of deposited contaminants.

4. ***Influence of acidic precipitation on wetland function and water quality:*** Changes in wetland pH due to acid precipitation likely affect the function and water quality of wetlands (Gorham et al. 1984). Depressed surface water pH mobilizes metals that are bound out of solution. It is suspected that acidic precipitation is causing the release of metals and other substances (that are normally bound at higher pH) to surface waters. Of particular interest is the release of harmful metals such as aluminum. While peat itself does not contain much aluminum (only what comes in via air and water), there is some concern that drinking water supplies in wetland areas may be contaminated by accelerated release of deleterious substances from wetlands. DOC may also be affected by acidic precipitation; a fact which would thereby alter wetland function. More basic research is needed to better understand the acid-base properties of wetlands, the issue of surface water contaminants, and the role of DOC.

Little is known of the relative sensitivity of wetland types to acid precipitation. Of particular concern is the sensitivity of poor fens (Gorham et al. 1987). Studies also need to be undertaken to assess the sensitivities of wetland types to acidic precipitation.

3.3 Land Use

The third major category of human activity is comprised of the activities that affect wetlands directly. These include activities associated with agriculture, forestry, industry, urbanization and road building. While the focus of this section is on the effects of human activity on wetland geochemistry and hydrology, the link is also made between these (physical and chemical) effects and terrestrial and aquatic wildlife habitat. We are interested in both the direct effects of these land use activities on wetlands, and on the indirect effects of modified wetlands on adjacent and downstream areas.

3.3.1 Land Use Activities

The general land use activities of concern to wetlands in Canada are listed below.

1. Agricultural Development
   - drainage practices
   - seasonal exploitation
2. Urban Development
   - fill disposal
3. Harvesting
   - peat and trees
4. Impoundments
5. Prescribed Burning
6. Roadbuilding

1. ***Effects on water table:*** Long-term regional studies which investigate the effects of land use on surface water quality and hydrology are needed. Information from such studies will be useful for developing mitigative strategies for future development in unaffected areas. Of particular concern are the activities of filling and draining wetland areas, and the effects of land clearing. These activities are suspected to have far-reaching effects on wetland water quality and hydrology.

Changes to water availability and local hydrology will affect surface water quality both within and downstream of wetland areas. Wetland areas act as discharge and recharge sites for regional water tables, thus impacts on wetland surface water quality and hydrology may also impact water table levels and water quality. Similarly, because wetlands are dependent upon water table height and quality, land use activities which affect the water table in upland areas may also affect wetlands below the activity through its effect on surface waters and the water table. Water resources in lower basin areas are affected by permanent changes in upper basin hydrology. Changes to basin hydrology affect both the magnitude and frequency of flooding in lower basin areas, as well as the amount of water available for discharge during dry periods.

2. ***Cumulative effects on wildlife resources:*** Land use practices which physically alter wetland areas directly affect the wildlife that depend on wetlands for part or all of their life cycles. Waterfowl and fisheries resources, as well as some furbearers, are particularly vulnerable to wetland loss or impairment. The effects of land use practices on the structure and distribution of wetlands are relatively easily to detect compared to their effects on wildlife populations.

   Wetlands, especially shoreline wetlands, are an integral component of the structure of aquatic communities. They are considered to be centres of ecological organization for fish communities (Steedman and Regier 1987). Wetlands are used for reproduction, early rearing, feeding and protection by aquatic and terrestrial wildlife. Only recently has it been realized that wetland losses over the decades have caused permanent changes in the structure of aquatic communities. Wetland areas also comprise the critical ecotone between terrestrial and aquatic environs. It is these areas that exert profound, yet not well understood, controls on ecosystem resiliency and health.

3. ***Long-term response to agricultural development:*** Studies are needed to investigate the effects of agricultural development on prairie wetlands (particularly the effects on structure and distribution of prairie potholes and the wildlife that depend on them). Studies are also needed to assess the resiliency of these ecosystems to various seasonal agricultural practices such as fertilization, tillage, planting, and harvesting.

4. ***Response of wetlands to urban runoff:*** Wetlands are often used as drainage areas for storm sewer discharge points, especially in areas where an urban centre is adjacent to a large river or lake. Studies are needed to determine the fate and effects of contaminants originating from urban runoff on wetlands and wildlife.

5. ***Efficacy of "no net loss" policies:*** Current policy (e.g. Department of Fisheries and Oceans' Policy for the Management of Fish Habitat) requires developers to replace any wildlife habitat destroyed through development so that no net loss of habitat occurs. This habitat may be reconstructed at that site or elsewhere. The effectiveness of such policies for wetlands and wildlife habitat

needs to be investigated. Long-term post development monitoring is necessary in order to determine whether we can actually replace "like for like" in other locales.

Adequate replacement is highly improbable for peatlands that have developed through complex successional processes over thousands of years, particularly where landscapes have become strongly patterned as a result of extremely delicate interactions between vegetation and hydrology (e.g. Glaser et al. 1981, Janssens et al. in press).

4.0 Information and Research Needs Relating to Wetland Habitats

Wetlands are distinct from the upland and aquatic ecosystems that surround them. They provide essential habitat to many vertebrate, invertebrate, and plant species (Gorham 1990). As a group we identified the following four research areas which, when studied, would provide valuable information for managing wetland habitat. These are:

- ecological dynamics;
- limiting factors affecting the distribution of organisms;
- wetland interactions with other habitats; and
- restoration and preservation.

Each of these research areas will be discussed in detail below.

4.1 Ecological Dynamics

We were primarily concerned with the processes that affect the conditions of wetland habitat and the suitability of wetlands to support wildlife. These are:

- the carbon, nitrogen, phosphorus and sulphur cycles;
- population dynamics of plants and animals that control biodiversity; invertebrate dynamics are in special need of investigation; and
- wildlife response to altered hydrology, and to other wetland habitat changes.

4.1.1 The Carbon, Nitrogen, Phosphorus and Sulphur Cycles

The element cycles define the structure of wetland habitats. They are important factors in the growth and stability of plant, invertebrate and vertebrate populations. Our discussion focused on these attributes of the element cycles, and included the indirect influence of the element cycles on the rate of peat accumulation and subsequent effects on wetland habitat structure. The research associated with the cycling processes should:

1. ***Identify the relationships between the carbon, nitrogen, phosphorus and sulphur cycles and the success of plant, invertebrate and vertebrate populations:*** There is an outstanding need to further explore the cycling processes of carbon, nitrogen, sulphur and phosphorus in Canadian wetlands. This need is especially pronounced in the southern freshwater wetlands and northern peatlands. Such studies should include investigation into important below ground processes that involve the microbial actions that influence element cycling processes.

   There is also a clear need to determine the role of the element cycles in the population dynamics of wetland wildlife. The quality of habitat, in terms of its ability to support vegetation, invertebrates, and vertebrates is intricately tied to

the element cycles. Since the first two population types are the food source for many vertebrate species of wildlife, the success of these prey species is vital. An improved understanding of these cycles will allow researchers to determine the relationship between wetland biodiversity and element cycling processes.

2. ***Within the carbon cycle determine how the rate of peat accumulation affects habitat structure:*** The carbon cycle is known to be an important component in the production of peat. Since peat is a significant factor in defining the habitat structure of wetlands, the role of the carbon cycle in peat growth and accumulation must be studied further.

4.1.2 Population Dynamics of Plant and Animals

Our discussion explored how wildlife use wetland habitat and how habitat use by one species affects habitat use by another. The specific research areas that were identified are:

1. ***Link wetland characteristics to wildlife and determine which species prefer which types of wetlands:*** Resolution of #1 in Section 4.1.1 will indicate which prey species will be present in particular wetland habitat types. This information can then be used to identify which predator species should also be present in that wetland habitat. In addition, the structure of wetlands, in terms of shape, vegetation cover, and amount of peat, will directly influence the species of wildlife that are present.

2. ***Define the interactions that occur among wildlife species:*** Investigations are required to document and explain the wetland food chain and, in particular, determine why:

   - certain species are dominant in particular types of wetlands;
   - certain species are transient in particular types of wetlands; and
   - rare and threatened wildlife thrive only in particular wetland types.

The role of invertebrates in the wetland food chain was identified as an area dominated by significant gaps in information. Research must, therefore:

3. ***Examine invertebrate interactions with predators and with wetland geochemical and water flow processes:*** The invertebrates anchor the food chain and are, therefore, extremely important as a food source. It is the diversity of invertebrate life in a wetland that draws the diversity of predators to wetland habitats. The invertebrates are strongly tied to the vegetation chemistry and water flow regimes in wetlands and are stressed by disturbances of them. Invertebrates, therefore, have utility as bio-indicators of wetland disturbance. The earlier discussions of geochemical and water flow processes will elucidate information that can be used to investigate which wetland processes are tied to invertebrate population dynamics.

4.1.3 Wildlife Response to Alterations in Hydrology and to Other Changes in Habitat

Wetland disturbance can produce many dynamic system alterations, including: changes in species composition; alteration and loss of structure or function; and destabilization of interactions with other ecosystems in the biosphere (Gorham 1990). In all cases the disturbance may be generated from natural or anthropogenic sources, although the anthropogenic changes often cause more severe effects.

As direct human disturbances increase (e.g. draining, damming, hydro projects, pollution, forestry, agriculture, etc.) and natural disturbances become less predictable owing to indirect effects of human activities (e.g. global warming, chemical interactions resulting from pollution sources) an understanding of the effects of wetland disturbance becomes indispensable. Before we can manage wetlands for disturbance scenarios, we need to conduct research in order to understand:

1. ***How various species of wildlife respond to wetland alterations at a series of levels:*** This is a large and complicated issue that must address the alteration of different habitat components (e.g. change in vegetation structure, change in food source, altered pH, etc.) from the molecular level to the ecosystem structure level. An understanding of how different wildlife respond to the disturbance of different habitat attributes at different levels of resolution will allow managers to predict the effects of disturbance regimes in wetlands.

2. ***Indirect interactions must also be explored:*** Although a disturbance may not directly affect a predator species, it may produce an indirect effect by stressing the prey species that it feeds upon. These dynamic food chain associations should be documented.

4.2 Limiting Factors Affecting the Distribution of Organisms

Our discussion of those factors which limit the distribution of organisms also focused on those which limit their abundance and productivity. These limiting factors were identified as:

- precipitation and temperature (including drought);
- nutrients;
- acid/base balance and salinity;
- hydrology; and
- species interactions and wetland size.

4.2.1 Precipitation and Temperature

Although wildlife are adapted to "normal" variations in atmospheric conditions, they can be sensitive to extreme events which lead to unusual disturbances in the habitat processes. Research is required to:

1. ***Identify how atmospheric events make wetland habitats unsuitable or limiting to wildlife:*** Weather events may limit the suitability of habitat for a particular species and, in turn, limit the distribution, abundance, and productivity of wildlife. The effect of habitat alteration for a particular species is dependent upon that species' unique tolerance to habitat changes. Weather related factors that limit habitat suitability are:

   - residence time of snow packs;
   - amount of sunlight received;
   - length of growing season; and
   - variation between the diurnal minimum and maximum temperatures.

   Studies should investigate the reasons why a habitat becomes unsuitable for sensitive species after a significant atmospheric event.

4.2.2 Nutrients

The survival of invertebrates and plants is dependent upon the availability of prerequisite nutrients. Studies must, therefore, be conducted to determine:

1. ***The minimum nutrient requirements for selected plant and invertebrate species in various wetland types:*** Since the availability of nutrients affects the health and vigour of plants and invertebrates, any process that limits the supply of essential elements and minerals will affect the ability of these wildlife to survive.

4.2.3 Acid/Base Balance and Salinity

Our discussion considered how fluctuations in pH and/or salinity may limit habitat suitability for wetland wildlife. The associated research need is to determine:

1. ***How various wetland types with specific acid/base and salinity characteristics limit wildlife habitat suitability and consequently, the survival of specific wildlife species:*** Although the acid/base balance and salinity characteristics primarily limit plants and invertebrates, they may also influence habitat suitability for vertebrates (e.g. amphibians and some waterfowl). Many species have very specific pH, DOC and salinity requirements and are, therefore, absent from any wetland habitat that does not meet these requirements.

4.2.4 Hydrology

Hydrology was discussed not as a process but as a component that may limit habitat suitability. Different wetland habitats have different characteristic flow regimes which, in turn, dictate the suitability of habitat for wildlife. Research should address:

1. ***How various wetland types with specific flow characteristics limit wildlife habitat suitability:*** The nature of the flow (e.g. velocity, volume, depth below the surface, water table fluctuations, etc.) and the nature of water levels were identified as the major hydrological factors influencing the suitability of a wetland habitat for wildlife.

4.2.5 Species Interactions and Wetland Size

This section addresses those factors which render a particular wildlife species dominant in a wetland habitat. While we recognized that dominance is the result of many dynamic variables, we addressed dominance at the simplest level. Firstly, we considered the relationship between habitat size and the success of a species. Secondly, we investigated the interactions that occur between species in a wetland habitat in order to determine how one species out-competes another. The research must, therefore, consider:

1. ***How the dominant wildlife species in a wetland habitat maintain their dominance at the large and small vertebrate level, plant level, and invertebrate level:*** This discussion is intricately linked with Section 4.1.2 and addresses how the presence of certain species in a wetland habitat will limit or restrict the colonization by other wildlife. The dynamic interactions among wildlife species have not been addressed as fully for wetlands as they have for many other upland habitat types. It should be noted that the issue is vast with many components and must, therefore, be tackled piece by piece over an extended period of time.

2. ***Determine minimum area requirements for wetland wildlife:*** A factor that could have a substantial impact on habitat suitability is the size of the wetland. Many larger vertebrate species have minimum area requirements and are only dominant in those habitats that meet these requirements.

4.3 Wetland Interactions with Other Habitats

Many upland and aquatic habitats surround, influence, and interact with wetlands. As a result, it is important to investigate how these surrounding habitats affect wetland habitats and whether the effects are predictable.

In general, the two broad categories of "other habitats" discussed were natural habitats and anthropogenic habitats (habitats created or altered through human use). The issues that emerged from the discussion of natural habitats include:

- upland habitats;
- aquatic habitats; and
- atmospheric influences.

Our discussion of anthropogenic habitats focused primarily on how human disturbances in neighbouring habitats has:

- affected the processes in the wetlands;
- led to the inflow of unusual quantities of nutrients; or
- increased contaminant levels.

The issues discussed include:

- drainage alterations;
- habitat alteration and land use change;
- waste water; and
- atmospheric and stream deposition.

4.3.1 Natural Habitats

Our discussion considered how the inputs (water, nutrients, toxins and biota) from upland and aquatic habitats affect wetland ecosystems. It is also important to define the nature of the outputs from the wetland to surrounding habitats and to determine whether the type of adjacent habitat affects the nature and composition of that output. A great deal of knowledge needs to be gained in order to help explain how different habitat types interact with wetlands. The research needs are to:

1. ***Identify the variety of wetland habitats that exist in Canada and define how their characteristics differ:*** Different wetland habitats will have different nutrient cycling processes, biota, toxins and flow regimes. This will obviously influence the species of wildlife found in that wetland and, therefore, the wildlife interactions that occur between neighbouring habitats. A documentation of how wetland habitat types differ will help explain wildlife presence/absence and inter-species interactions.

2. ***Determine whether particular ecosystem types adjacent to a wetland affect the wetland output and wetland internal processes:*** A need exists to identify how different upland and aquatic habitats affect wetland output and influence wetland processes.

3. ***Determine what form of precipitation most significantly affects wetland processes (e.g. fog, thunderstorm, snow, etc.) with respect to water levels and chemical inputs. Determine whether the type of atmospheric event and intensity of the event affect wetland processes:*** Atmospheric water and chemical inputs must be identified and linked with the wetland processes that may be affected. If atmospheric inputs play a role in wetland processes, research must be conducted to determine the significance of the form of precipitation.

4.3.2 Human Induced Drainage Alterations

Activities such as agriculture, forestry, peat mining, hydro projects, and road building can significantly affect natural flow regimes and, therefore, alter the flow of water into the wetland. The use of machinery, the removal of native vegetation, and extensive land management are the primary mechanisms that influence flow from disturbed habitats. Research (including diverse experiments on natural wetlands) should lead to:

1. ***At least a rudimentary understanding of how particular land use activities adjacent to wetlands affect water inflow rates into the wetland.***

4.3.3 Human Induced Habitat Alteration and Land Use Change

Human activity will directly alter the structure of, and processes in, the habitat in which the activity occurs. It may also indirectly disturb the nearby habitats. Obviously, the nature of habitat alteration is a function of the land use activity. Refer to Section 4.1.3 for a discussion of wetland habitat alteration and research needs.

4.3.4 Atmospheric and Stream Deposition

There is considerable concern about the pollution of wetlands through atmospheric or effluent discharge. Pesticides used in forestry and agriculture and the airborne pollutants from industrial sources make their way into even the most remote wetland. In addition, the removal of vegetation through forestry and agriculture often leads to increased sediment loading in streams that flow into wetlands. The areas of research that emerged from this discussion are:

1. ***How do the most common chemical pollutants interfere with "normal" wetland processes:*** How do pollutant induced changes to wetlands affect habitat characteristics such as pH, DOC, nutrient loads, and plant, invertebrate, and vertebrate composition?

2. ***How do increased loads of dissolved solids and sediments affect wetland processes and does this influence the vegetation communities within a wetland habitat:*** This research need examines whether vegetative growth and survival rates are affected by altered element cycling processes, altered pH and DOC levels and/or the changed water flow properties that may be associated with increased sediment loading.

4.4 Wetland Restoration/Preservation

Given that wetlands are a unique, dynamic and essential habitat to many wildlife species, research efforts must be devoted to restoration and preservation issues. The issues that were flagged as most important to this discussion include:

- understanding wetland successional trends in order to identify valuable wetland sites; and
- the development of wetland restoration technology.

4.4.1 Wetland Succession

It is reasonable that the most valuable (in terms of unique properties and importance to wildlife) wetlands should be protected first. However, until it is determined at which point in the successional cycle wetlands are the most valuable to wildlife, it is difficult to know which wetlands are, or will be, important as habitat. The research task is:

1. ***Through the use of chronosequences and paleoecology techniques, develop an understanding of the successional trends of wetlands and document which stages of succession are the most important to the different wildlife species:*** This task will require:

   - construction of successional pathways for wetland habitats; and
   - association of wildlife with a habitat that is at some definable point in its successional path. This in turn will allow managers to determine which successional stages are preferred by the species of concern.

   In this connection, analysis of fossil bryophytes in dated peat cores now permits the construction of depth and age profiles for inferred pH and height of the peat surface above mean water table (Janssens 1990, Janssens et al. in press).

4.4.2 Wetland Restoration

As wetland loss becomes more of a concern, knowledge of how to restore disturbed wetlands becomes invaluable. Restoration is a tricky science that requires an understanding of which components of a disturbed wetland need to be restored to achieve a desired result. Caution should be exercised during restoration activities in order to ensure that the restoration is actually "improving" the wetland and not destroying it. In order to identify which habitat components have been altered and which must be restored, a thorough understanding of wetland habitat processes is essential. Therefore, research must:

1. ***Develop the ability to predict how particular disturbances will influence a wetland system. Develop restoration technologies that will restore wetland processes:*** Experimental ecosystem manipulation must be conducted in order to identify how drainage regimes, acid/base balances, energy balances, and nutrient cycles may be disturbed and restored. As restoration technologies are developed we must also acquire an ability to predict exactly how wetland processes and interactions will be altered in response to various disturbance regimes. We will never be sure that restoration is successful until it is proven through experimentation that geochemical and wildlife processes can be manipulated to a predictable point.

5.0 Recommendations

The information needs identified in the previous sections result from a broad, but brief examination of issues and ongoing work on wetlands in Canada. The most efficient way of providing the needed information is by taking an integrated approach to research rather than conducting a series of independent research and monitoring efforts. Similar broad and integrated management approaches need to be adopted to deal with the inter-related nature of the suite of problems facing wetland and environment managers.

Each of the recommendations made at the workshop generally relates to one of two types of activities needed to support research on wetland ecology, management and restoration:

1. developing infrastructural and organizational services and capabilities; and

2. developing inventory, monitoring and research tools and mechanisms.

Although these categories of activities are not entirely discrete, they do form a useful framework for discussing the recommendations.

5.1 Infrastructural and Organizational Recommendations

1. ***Develop a national policy for protecting wetlands:*** Wetlands are being lost at a tremendous rate in some parts of Canada. Losses are particularly high where there are urban and agricultural land-use pressures that compete with the maintenance of wetland habitat. A national policy is needed for the specific purpose of protecting wetlands. Formal cooperation of the provinces must occur before such a national policy can be successfully implemented.

2. ***Establish a formal network to coordinate wetlands research in Canada:*** Although high-quality wetland research is being done in Canada, the overall advancement of knowledge could proceed more efficiently if efforts were more coordinated. A formal network comprised of scientists from university, government and private sectors should be formed to oversee the coordination of research efforts. It should be responsible for developing research priorities, and organizing regular symposia and training sessions. Such a network would have the advantage of ensuring that communication is maintained and that researchers are informed of related activities.

3. ***Develop wetland centres of excellence:*** The use of academic centres of excellence to facilitate research has proven to be an efficient mechanism for other scientific disciplines. Centres of excellence would provide good training grounds for researchers and would ideally form part of ongoing wetland research and management. The federal Department of the Environment could be involved

in providing management direction and input into determining research priorities. The centres of excellence would assist with developing research direction as well as actually carrying out a good deal of ongoing research.

4. ***Establish a subvention grant program for wetlands research:*** Subvention grants have been shown to be a productive mechanism for accomplishing natural-resource-oriented research. Wetland subvention grants would provide a mechanism for meeting some of the research needs identified in this report, and would also allow Environment Canada to contribute significant input into research directions.

5.2 Inventory and Monitoring

1. ***Integrate existing data into comprehensive databases:*** Much data on many aspects of Canadian wetlands have already been collected. Efficient use of this information is hindered by the fact that most data exist in scores of small and unique databases throughout the country. Greater use of existing information and less duplication of effort could be fostered by creating a centralized information facility. All existing data would not necessarily need to be integrated into one extensive database, but data should be centralized at one locale to permit easier and more efficient use. This task should also include the compilation of relevant climate and hydrological variables that may be used to facilitate investigations of the potential effects of climate change on wetland habitat.

2. ***Develop well-designed monitoring programs:*** In order to clearly understand how wetland processes react to disturbances and change over time, long-term monitoring projects must be established. The emphasis in this recommendation is that the programs must be well designed in terms of both statistical framework and landscape representation. The monitoring programs should, where possible:

   - be based on representative drainage basins and/or representative wetland complexes;
   - be integrated with existing meteorological and pollution monitoring programs;
   - include sites that are not affected by human activity so that components of wetlands that are sensitive to climate variables (e.g. air temperature, precipitation, CO_2) can be monitored;
   - incorporate monitoring of non-wetland habitats that influence wetlands (i.e. adjacent upland areas);
   - include assessment of peat reserves; and
   - include unique and exploitable wetlands.

3. ***Develop ecological and jurisdictional integration of classification systems:*** At present there are several land classification systems in use in Canada that are intended to be used solely for wetlands or that include wetlands along with other ecosystems. The boundaries of the classification systems are often political rather than ecological. Different wetland researchers often use different classification systems. The existing disparity of classification systems hampers efforts to integrate data, assess the state of wetland resources, and determine the effects of perturbations on wetland habitat. Effort should be devoted, therefore, to working towards the integration of existing classification systems. This activity may involve one or more of the following:

   - assessing the present classification systems;
   - developing a hierarchical classification system that would facilitate use at different spatial scales; and/or
   - developing or recommending the adoption of a classification system not constrained by geo-political boundaries.

4. ***Develop a comprehensive wetland inventory:*** In conjunction with the above activities, a comprehensive inventory of Canadian wetlands should be compiled. This will come about partially through fulfilment of #1. above. It will likely involve additional effort, however, including:

   - the development of one "inventory" database from existing databases; and
   - the analysis of existing databases to identify key missing information, and to eliminate the data gaps.

6.0 References

Boelter, D.H. and E.S. Verry. 1977. Peatland and water in the northern Lake States. North Central Forest Experiment Station, USDA For. Serv. Gen. Tech. Rep. NC-31. 22 pp.

Bolin, B., B.R. Doos, J. Jaeger, and R.A. Warrick (eds.). 1986. The Greenhouse Effect, Climate Change, and Ecosystems. SCOPE 29, John Wiley and Sons, Chichester, 530 pp.

Glaser, P.H., G.A. Wheeler, E. Gorham, and H.E. Wright. 1981. The patterned mires of the Red Lake Peatland, northern Minnesota: vegetation, water chemistry, and land forms. J. Ecol. 69: 575-599.

Gorham, E. 1990. Biotic impoverishment in northern peatlands. In: G.M. Woodwell (ed.). The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Woods Hole Research Center, Cambridge, Mass., pp 65-98.

Gorham, E., J.A. Janssens, G.A. Wheeler, and P.H. Glaser. 1987. Natural and anthropogenic acidification of peatlands. In: T.C. Hutchison and K. Meema (eds.). Effects of Atmospheric Pollutants on Forests, Wetlands, and Agricultural Ecosystems. Springer Verlag, Berlin, pp 493-512.

Gorham E., J.K. Underwood, F.B. Martin, and J.G. Ogden. 1986. Natural and anthropogenic causes of lake acidification in Nova Scotia. Nature 324: 451-453.

Gorham, E., S.E. Bayley, and D.W. Schwindler. 1984. Ecological effects of acid deposition upon peatlands: a neglected field in "acid-rain" research. Can. J. Fish. Aquat. Sci. 41: 1256-1268.

Harrington, J.B. 1989. Climate change and the Canadian forest. In: Proceedings of The Second North American Conference on Preparing for Climate Change: A Cooperative Approach. The Climate Institute, Washington DC. pp. 297-302.

Jaeger, J. 1988. Anticipating climate change. Environ. 30(7): 7.

Janssens, J.A. 1990. Methods in quaternary ecology--bryophytes II. Geoscience Canada 17: 13-24.

Janssens, J.A., B.C.S. Hansen, P.H. Glaser, and C.W. Barnosky. In press. Development of a raised bog complex in northern Minnesota. In: H.E. Wright, B. Coffin, and N. Aaseng (eds.). Patterned Peatlands of Northern Minnesota. University of Minnesota Press.

Jones, M.L., D.R. Marmorek, B.S. Reuber, P.J. McNamee, and L.P. Rattie. 1986. "Brown Waters": Relative importance of external and internal sources of acidification on catchment biota. LRTAP Workshop No. 5. Rep. prep. for Environment Canada and Dept. of Fisheries and Oceans. 85 pp.

Keddy, P.A. and A.A. Reznicek. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and seeds. J. Great Lakes Res. 12: 25-36.

Kellog, W.M. and Z. Zhao. 1988. Sensitivity of soil moisture to doubling of carbon dioxide in climate model experiments. J. Climate 1: 348-366.

Kessel-Taylor, I. 1985. An examination of alternative causes of Atlantic salmon decline and surface water acidification in southwest Nova Scotia. Preliminary Draft Report. Environmental Research and Integrated Programs, Lands Directorate, Environment Canada

MacDonald, G.J. 1989. Climate impacts of methane clathrates. In: Proceedings of The Second North American Conference on Preparing for Climate Change: A Cooperative Approach, The Climate Institute, Washington DC. pp. 94-101.

Meisner, J.D., J.S. Rosenfeld, and H.A. Regier. 1988. The role of groundwater in the impact of climate warming on stream salmonines. Fisheries 13(3): 2-8.

Moore, T.R. 1991. Methane emissions from peatlands. Presented at the workshop on Hydrogeochemistry of Wetlands. Canada Centre for Inland Waters, Burlington, Ontario, March 19-20, 1991.

Mortsch, L. (ed). 1990. Eastern Canadian Boreal and Sub-arctic Wetlands: A Resource Document. Canada Ministry of the Environment. Climatological Studies Rep. No. 42., 169 pp.

Prince, H.H and F.M. D'Itri. (eds.). 1985. Coastal Wetlands. Lewis Publishers Inc., Chelsea, Michigan.

Regier, H.A. and J.D. Meisner. 1990. Anticipated effects of climate change on freshwater fishes and their habitat. Fisheries 15(6): 10-15.

Rubec, C. 1991. Issues facing wetland scientists. Presented at the workshop on Hydrogeochemistry of Wetlands. Canada Centre for Inland Waters, Burlington, Ontario, March 19-20, 1991.

Schiff, H.I. and L.A. Barrie. 1988. A cooperative Canadian university government industry research program on "The Role of Canadian Wetlands in Influencing the Composition of the Atmosphere and Climate": a workshop report and three year program plan. Canadian Institute Res. Atmos. Chem., York University, Toronto, Ont.

Steedman, R.J. and H.A. Regier. 1987. Ecosystem science for the Great Lakes: perspectives on degradative and rehabilitative transformations. Can J. Fish. Aquatic. Sci. Spec Pub. 106. Rep. No. CIRAC/018801: 82 pp.

Taylor, C.H. and D.C. Pierson. 1984. Effect of variable source areas on cations delivery from a small wetland watershed. In: Proceedings of the Canadian Hydrology Symposium. Quebec City.

Woo, M.K. and J. Valverde. 1981. Summer streamflow and water level in a mid-latitude forested swamp. For. Sci. 27: 177-189.

Appendix 1: List of Workshop Participants

List of Workshop Participants

Name	Affiliation
Don Ambler	Environment Canada, Dartmouth, N.S.
Suzanne Bayley	University of Alberta, Edmonton, Alta.
Rick Bourbonniere	Environment Canada, Burlington, Ont.
Tom Clair (Chairman)	Environment Canada, Moncton, N.B.
Steve Eisenreich	Univ. of Minnesota, Minneapolis, MN
Egil Gjessing	NIVA, Oslo, Norway
Walter Glooschenko	Environment Canada, Burlington, Ont.
Valanne Glooschenko	Ont. Min. Natural Resources, Toronto, Ont.
Eville Gorham	Univ. of Minnesota, Minneapolis, MN
Robert Hélie	Environment Canada, Ottawa, Ont.
Harry Hemond	Mass. Institute of Technology, Cambridge, MA
Dean Jeffries	Environment Canada, Burlington, Ont.
Joe Kerekes	Environment Canada, Dartmouth, N.S.
James Kramer	McMaster University, Hamilton, Ont.
Elizabeth Langley	Environment Canada, Dartmouth, N.S.
Bruce Lazerte	Ont. Min. Natural Resources, Dorset, Ont.
Rick Lawford	Environment Canada, Saskatoon, Sask
Don Meisner	ESSA Ltd, Richmond Hill, Ont.
Tim Moore	McGill University, Montreal, Que.
Wally Nicholaichuck	Environment Canada, Saskatoon, Sask.
Jonathon Price	Queens University, Kingston, Ont.
Michael Rose	ESSA Ltd, Richmond Hill, Ont.
Nigel Roulet	York University, North York, Ont.
Bob Rowsell	McMaster University, Hamilton, Ont.
Clayton Rubec	North American Conservation Council (Canada)
Dale Vitt	University of Alberta, Edmonton, Alta
Barry Warner	University of Waterloo, Waterloo, Ont.
Chris Wedeles	ESSA Ltd, Richmond Hill, Ont.
John Wood	Environment Canada, Regina, Sask.
Steve Zoltai	Forestry Canada, Edmonton, Alta.

Appendix 2: Abstracts of Papers Presented at the Symposium

Wetlands and Water Quality Concerns

Thomas A. Clair
Water Quality Br., Inland Waters Directorate-Atlantic Region
P.O. Box 861, Moncton, N.B. E1C 8N6, Canada

The purpose of this presentation is to a) offer an overview of complications to water quality interpretation caused by dissolved organic acids in waters draining wetlands, b) discuss why these problems occur, and c) to demonstrate the role played by brownwaters in global climate cycles. Most of the case studies discussed here will be based on surface waters of Canada's Atlantic Canada, but can be generalized to most northern temperate areas with poor drainage.

Wetlands effects on water quality are much greater than could be guessed, based solely on their areal distribution. Though wetlands occupy only approximately 15% of the Atlantic Provinces, approximately 50% of lakes and rivers in the region show relatively high colour levels, indicative of natural organic acids (NOA), measured as dissolved organic carbon (DOC) produced in wetland soils. NOA complicate the interpretation of a number of water chemistry problems.

At natural pH values, NOA is negatively charged, thus playing an important part in water's ion balance equation. Until recently however, there were no techniques available for the direct measurement of organic anion charge of waters, and thus values had to be estimated indirectly. This problem has been the cause of much confusion in the past, and will only be resolved when direct measurements become commonly available. Another complication brought about by NOA charge is its potential for complexing metals. Once complexed, ions of aluminum, iron, manganese and other metals are no longer part of the charge balance. However, once more, few analytical methods are available which allow separation of ionic from complexed forms. The presence of NOA has also tended to complicate the interpretation of anthropogenic acidification effects. Novel ways of estimating the relative importance of organic and mineral acidification have had to be developed in order to predict how changes in mineral acid inputs would change the pH of brownwaters.

The presence of brown waters in public water supplies has tended to bring on a number of problems to communities dependant on surface water reservoirs. Traditionally, public health engineers have viewed NOA as potential refuges and nutrient supplies for bacteria. Early treatment of brownwaters usually included higher levels than usual of chlorine. Work from the late 1960's has shown that this approach tends to lead to the formation of trihalomethanes. In a survey of 86 public water supplies in Atlantic Canada, most were shown to contain measurable THM levels (Environment Canada 1989). Removal of NOA from water supplies can be a costly enterprise however, as use of filtration, coagulation with alum or other methods add considerable expense to the treatment of drinking water.

Despite a great deal of effort, few direct correlations have been drawn between NOA or DOC concentration in surface waters and the effects described above. The reason for this resides

in the fact that NOA is not an easily described compound, but tends to be composed of macromolecules randomly formed in soils and in waters. These macromolecules are further modified by adsorption processes of soils as well as biological degradation. Recent work in Nova Scotia shows that there are large differences in both acid-base and structural chemistry of NOA, which vary depending on the environment of formation, as well as with season. More work needs to be done defining both the chemistry of formation and modification of NOA in wetland soils, as well as its acid-base chemistry before we can start predicting metal complexation reactions, THM formation, or even simply DOC concentration in surface waters.

Surface waters draining wetlands may also play an important role in modifying global carbon fluxes. Using data from large river systems, Degens et al. (1984) and Kempe (1988) have calculated that $0.11X10^9$ tC/a of DOC are transferred from land to ocean by rivers. Once in oceans, carbon is either further oxidized to CO_2 by microbial and other biological activity, or is buried in sediments. An understanding of the canadian situation and studies of other published data suggests that the carbon export numbers generated by Degens et al. (1984) may not be very accurate. Canadian rivers discharge almost 10% of the planet's freshwaters into the ocean, (Can. Hydrol. Atlas 1978). The sites used to generate the above data only included 35% of North American river water, concentrating on six of the largest, including the Mississippi, the St. Lawrence and the Mackenzie. Those data suggested that the continent watersheds yielded approximately 0.8 tC/km^2 DOC per year. Based on data from Atlantic Canada, these values are probably much too low. For example, four rivers from which have been studied since 1980, yielded between 13 and 184 tC/km per year of DOC. These kinds of values can conceivably apply to most northern and eastern coastal rivers of North America.

References:

Canadian Hydrological Atlas (1978) Fisheries and Environment Canada, Ottawa, Canada.

Degens, E.T., S. Kempe, V. Ittekkot (1984) Monitoring carbon in world rivers. Environment 26: 29-33.

Environment Canada (1989) Atlantic Region federal-provincial toxic chemical survey of municipal drinking water sources 1985-1988. Inland Waters Directorate, Environment Canada, Moncton, N.B..

Kempe, S. (1988) Freshwater carbon and the weathering cycle. In: A. Lerman, M. Meybeck (eds) Physical and Chemical Weathering in Geochemical Cycles. pp. 197-223. Kluwer Acad. Pub.

HYDROLOGY OF PEATLANDS

A wetland is defined as land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, etc. The essential character of wetlands is controlled by hydrological processes which maintain a high water table. Local hydrological conditions control the development of wetlands, and the wetlands in turn control some hydrological processes.

Peatlands are a broad class of wetland that are characterized by the accumulation of incompletely decomposed plant material. They most frequently occur where summer temperatures are warm enough to produce sufficient biomass, but cool enough to limit decomposition. The state of decomposition increases with depth, resulting in low hydraulic conductivity in the underlying permanently saturated catotelm, which is overlain by partially decomposed, dead and live plant material in the acrotelm. The water table normally resides in the acrotelm, which has a much higher hydraulic conductivity. The contrasting hydraulic properties of the acrotelm and catotelm is an important feature of many peatlands, and controls the rate and character of runoff and evapotranspiration.

Peatlands can be sub-categorized based on the nature of their relationship with the regional groundwater regime. Swamps and fens are peatlands connected to the regional groundwater system, and may receive surface and groundwater inflow for some or all of the year. Mineral-rich water inflow sustains a variety of transpiring plants, and maintains a higher water table during summer. This enhances evaporation and transpiration losses, but the relatively high water table diminishes the water storage deficit during dry periods, hence their ability to attenuate flood peaks. Continued groundwater recharge from adjacent mineral terrain during dry periods may be transmitted through these systems, thereby sustaining streamflow. Bogs are ombrogenous (rain fed) peatlands typified by a perched water table, which by virtue of their own peat accumulation have isolated themselves from the regional groundwater system, and the mineral nutrients it supplies. Water table fluctuations are generally more extreme than in groundwater connected systems, reflecting the episodic nature of water inputs. Runoff ceases when the water has drained from the acrotelm, since flow through the catotelm is extremely slow. Flood peak attenuation is only effective following dry antecedent conditions when evaporation lowers the water table below the critical depth at which runoff ceased. Evaporation from the oligotrophic non-vascular vegetation typical of bogs is also closely related to water table elevation, since there is no effective mechanism to transport water through the acrotelm from the zone of saturation to the surface.

Wetlands are often considered to attenuate flood peaks, and sustain baseflow during dry periods. However, the large water storage in peatlands is dominated by the small dynamic storage capacity in the zone above the water table. Only patterned peatlands, which have a large depression storage capacity, can significantly and consistently delay flood passage. Otherwise, flood attenuation is strongly dependent on antecedent conditions, just as it is in non-wetland areas. Sustained baseflow occurs only in groundwater-connected wetlands, and that flow is possible because of recharge from non-wetland areas.

The basic hydrological processes of peatlands summarized above can be regionalized to reflect various climatic conditions which exist in Canada. Wetlands of the low, mid and high arctic are constrained by low precipitation conditions, occurring only in topographic locations where water inflow enhances local precipitation. They are typically characterized as fens, where surface water input from late lying snowpacks, overflowing lakes, and hillslope drainage is retained near the surface because of the underlying permafrost. The high water table results in poor water storage capacity, so runoff is flashy. Most of the annual runoff occurs during the main snowmelt period. Evaporation may be important during summer, but is much smaller than runoff on an annual basis.

In subarctic and boreal areas, precipitation is considerably higher than in the arctic, so peatland development is not as constrained by topography, and bogs may form as well as fens. The nival period is important in producing runoff, but summer storms can generate the annual maximum flood if the antecedent conditions are wet. Warmer summers enhance evaporation, which may equal or exceed runoff on an annual basis. Higher evaporation, coupled with deeper or absent ground frost results in an erratic water table, and runoff may cease from bogs in summer. Cold winters in the arctic and subarctic peatlands generally preclude winter runoff.

Maritime wetlands are influenced by high precipitation, and cool, moist air which suppresses evaporation. The seasonal excess of rain over evaporation during the summer promotes surface saturation, hence wetland development. Bogs therefore occur more frequently. The generally high water table keeps maritime peatlands primed to produce discharge after each rain event, and runoff may occur throughout the summer, even from bogs. Fog plays an important role in some coastal peatlands, supplying a significant quantity of water to the system, and severely restricting evaporation. Frequent winter rain and thaw periods can also produce runoff.

Temperate wetlands of the lower Great Lakes-St. Lawrence Lowland area are typically treed swamps. Here, evaporation rates are significantly higher, and interior wetlands are mostly groundwater-connected. Streamflow regimes are dominated by the groundwater discharge into the swamp, which can sustain flows much greater than local rainfall alone could produce, and which provides baseflow year round. The high water table limits the storage capacity of such wetlands, and snowmelt and rainfall events can generate significant runoff peaks.

The hydrological behaviour of peatlands has marked similarities to non-wetland basins, being controlled by lateral and vertical water transfers with the surrounding environment. As such, their runoff regime can be explained by current runoff theory. The role of groundwater-connection is complex, and such wetlands are less well understood. The vertical transport of water through the acrotelm in response to evaporation is one of the least understood processes, yet this linkage is essential to evaporation and carbon transfer to and from the system.

NORTHERN WETLAND STUDY (NOWES)[1]

Nigel T. Roulet, Department of Geography, York University, 4700 Keele St., North York, Ontario M3J 1P3

The Northern Wetlands Study (NOWES) is a multidisciplinary investigation designed to assess the importance of northern wetlands as a source/sink of biogenic gases to the atmosphere (Roulet et al. 1991). The primary emphasis of the study was on the exchange of CH_4 and CO_2 between wetland ecosystems and the atmosphere, but the fluxes of N_20, NO_x, VOC, and DMS were also examined. The characterization of variations in trace gas source/sink dynamics as a function of wetland hydrology and soil temperature will also provide a basis for modelling the effects of future climate change scenarios on regional feedbacks. The specific objectives of NOWES are:

1 to investigate the atmospheric chemistry of biogenic gases and related compounds from northern wetlands with emphasis upon carbon gases;

2 develop an understanding of the physical, chemical, and biological processes that influence biogenic gas production and exchange and the sensitivity of the source/sink to climate change;

3 determine the significance of northern wetlands as a source of biogenic gases to the atmosphere globally; and,

4 characterize the trace gas exchange in the context of the present and past ecology of northern peatlands.

The Canadian Institute for Research in Atmospheric Chemistry (CIRAC) and the National Aeronautics and Space Administration (NASA) are the lead agencies coordinating the project. Eight universities and eleven government agencies from Canada, and ten universities and three government agencies from the United States are collaborating on the study.

The principal field effort for the Canadian portion of the study was on the Hudson Bay Lowland, the second largest continuous wetland (27,000,000 ha) in the world. The study made flux measurements along a 100 km transect from the coast of James Bay inland to the interior

---

[1] This is Scientific Contribution 91-1 of the Canadian Institute for Research in Atmospheric Chemistry (CIRAC, York University Campus, 4700 Keele St., North York, Ontario M3J 1P3). The work described herein was undertaken as part of the CIRAC Northern Wetlands Study (NOWES) which was funded in part by the Natural Sciences and Engineering Research Council of Canada and Atmospheric Environment Services, Environment Canada.

of the Lowland. This transect follows approximately 5,000 years of peatland succession. A second Lowland site, located near Churchill, Manitoba, represented the permafrost portion of the Lowland. The main site for the American effort was in the subarctic/boreal region of Quebec and Labrador where the wetland coverage is discontinuous (27% coverage). This study was conducted by NASA Atmospheric Boundary Layer Experiment (ABLE-3B) project.

Research activities at both sites included flux measurement programmes using chambers, towers, and aircraft. These measurements were supplemented by studies of the factors that control the gas flux using both in situ and laboratory experiments. In addition to biogenic gas flux, research was undertaken to characterise the chemistry of the troposphere above the ecosystems. This work included studies on changes in tropospheric composition as a result of biomass burning, low ozone events, and influx of polluted southern air masses. Land characterization by remote sensing and ecology is being used to develop a classification for the spatial extrapolation of the results to estimate the contribution of continuous and discontinuous northern peatland areas to the trace gas composition of the troposphere.

Preliminary studies and reconnaissance were undertaken in 1989 and the main experiment took place last summer (1990). The study has just completed a workshop where the major findings were discussed (February, 1991) and the principal investigators are preparing presentations (eg. den Hartog et al. 1991; Desjardins et al. 1991; Edwards et al. 1991; Glooschenko et al. 1991; Hamilton et al. 1991; King et al. 1991; Moore et al. 1991; Roulet et al. 1991b; Schiller et al. 1991) for a special Atmospheric Sciences session at the spring meeting of the American Geophysical Union. This will be followed by a dedicated issue of the Journal of Geophysical Research.

References

den Hartog, G., H.H. Neumann, A. Chipanshi, and K. King, 1991. Carbon dioxide flux and energy balance measurements using micrometeorological techniques at the Kinosheo Lake tower site during the NOWES experiment. **EOS** (in press).

Desjardins, R.L., H. Hayhoe, P.H. Schuepp, and J.I. MacPherson, 1991. Spatial and temporal variability of CO_2, sensible and latent heat fluxes over the Hudson Bay Lowland. **EOS** (in press).

Edwards, G., H.H. Neumann, G. den Hartog, G. Thurtell, and G.E. Kidd, 1991. Eddy correlation measurements of methane fluxes using a Tunable Diose Laser at the Kinosheo Lake tower site during the NOWES experiment. **EOS** (in press).

Glooschenko, W.A., L.A. Barrie, N.T. Roulet, and H.I. Schiff, 1991. The Northern Wetlands Study (NOWES): An overview. **EOS** (in press).

Hamilton, J.D., C.A. Kelly, and J.W.M. Rudd, 1991. Methane and carbon dioxide flux from ponds and lakes of the Hudson Bay Lowland. **EOS** (in press).

King, K.M., and the NOWES Science Team, 1991. CO_2 exchange between a northern wetland and the atmosphere by surface, tower, and aircraft - based measurements. **EOS** (in press).

Moore. T.R., A. Heyes, S. Holland, W.R. Rouse, N.T. Roulet, and L. Klinger, 1991. Spatial and temporal variations of methane emissions in the Hudson Bay Lowland. **EOS** (in press).

Roulet, N.T., and the NOWES Science Team, 1991. The role of the Hudson Bay Lowland as a source of atmospheric methane. **EOS** (in press).

Roulet, N.T., L.A. Barrie, W.A. Glooschenko, R.C. Harriss, K. Higuchi, J.I. MacPherson, T.R. Moore, H.H. Neumann, R. Protz, and H.I. Schiff, 1991. Northern Wetlands Study: An assessment of the role of northern wetlands in the exchange of atmospheric trace gases. **Ecological Bulletin (Sweden)** (in press).

Schiller, C.L., D.R. Hastie, L.A. Barrie, and N.T. Roulet, 1991. Emissions of nitrous oxide and nitric oxide from the Hudson Bay Lowland. **EOS** (in press).

HYDROLOGY OF PRAIRIE WETLANDS

Robert D. Rowsell
Department Of Geography
McMaster University
Hamilton, Ontario
Canada L8S 4K1

There exists in the west central prairie region of Canada and the United States numerous wetlands which are unique in terms of their hydrology and biology. These regions are highly productive with respect to breeding waterfowl, and with increasing demand for arable land and possible changes in global climates, there is a need for better understanding of the interaction of these wetlands with their environment.

Previous work on prairie sloughs has concentrated on the groundwater flow system and its exchange with the slough. These studies suggested that groundwater recharge in these areas is the result of depression focused recharge, but little work has been conducted on the upland areas demonstrating how they contribute to the water balance of the slough. Previous water balance studies of prairie sloughs have dealt with the process of evaporation using a mass transfer method, which is not often physically based. A two year study of a slough in central Saskatchewan was undertaken to study the upland areas to estimate their contribution to the water balance of the slough and to obtain an estimate of evaporation from the slough and its surrounding area.

The snow storage in the upland area was 44 and 53 mm for 1989 and 1990 respectively, most of which was found on the lower slopes and under the trees. Melting of the prairie snowpack is often rapid, lasting 10 to 15 days, but it may sometimes be interrupted by cold periods and snow accumulation. A large portion of the water liberated by snowmelt in the upland areas is lost to sublimation and infiltration into frozen soil. During the summer period, the high infiltration rate of the upland areas enables most or all of rainfall to infiltrate into the soil and hence yielding little overland flow to the slough. Soil moisture profiles indicate little fluctuation below 1.5 m, showing that there is negligible downward movement of groundwater from these upland areas. The water that does infiltrate remains in the upper root zone (above 1.5 m) which is eventually lost to evaporation. This supports Lissey's theory of depression focused recharge.

In this study the slough comprised a pond and a wetland. Their relative areas change throughout the summer season as the areal extent of the pond decreases. Thus, instead of separating these two elements, the consideration of the slough as one unit reduces any error arising from the problem of variable area. Springtime water level in the slough is replenished by a rapid influx of excess snowmelt water from the upland areas in the form of overland flow. It is at this time that the slough experiences the highest water level of the year. It appears that overland flow from snowmelt is the only important source of slough replenishment from the uplands, as there is hardly any inflow during the summer. The presence of a standing water body in the slough during spring and early summer contributes the most to recharge. Groundwater

recharge from the pond has been found to be 3 orders of magnitude higher than the recharge from the wetland.

For the basin, it was found that the contributing area or the effective drainage area is much less than the topographic drainage area. The flat to undulating terrain of the prairie results in shallow depressions or low gradients at the upper reaches of a basin, therefore they do not contribute to the overall water balance. The spatial variation in snow cover results in variability of melt, infiltration and overland flow over the basin and therefore the melt process is best studied using a grid network. Rainfall was relatively uniform over the basin with higher amounts received for some events in the upland areas.

The water balance for the slough indicated that for the summer season evaporation was 137.5% and 147.1% of the total rainfall for 1989 and 1990. The corresponding values for groundwater recharge were 40.0% and 99.2% for 1989 and 1990. The reason for the difference in relative magnitudes for recharge is that in 1990, water remained in the pond longer and therefore contributed more to the summer water balance. For the period between the melt and the rest of the summer, the water loss to meteoric sources (evaporation and sublimation) was 92.5% of the total input (rainfall and overland flow) while recharge was 60.1% of the total . The percentage of rainfall consumed by evaporation for the upland areas during summer was 114.0 and 119.6% for 1989 and 1990. For the entire season in 1990, the loss of water to the atmosphere was 91.3% of the total precipitation while the loss to overland flow was 12.5%.

There is a need for more detailed studies of this nature for the many different types of wetlands which occur on the Canadian prairie. In addition to this there is a need for more long term monitoring to assess the impacts of climate change/variability on western wetlands.

HYDROLOGICAL - GEOCHEMICAL INTERACTIONS IN WETLANDS

by

Harold F. Hemond

For presentation at a workshop on the Hydrogeochemistry of Canadian Wetlands March 19, 1991

The unique geochemistry of wetlands is a direct consequence of their hydrological characteristics. This is because the transport of substances by and/or through water limits both the import and export of metabolic substances and pollutants. First, whether the soil is saturated or unsaturated has a dramatic effect of both the availability of O_2 and the export of volatile metabolites, due to the 4-order-of-magnitude difference in molecular diffusion rates between molecules in air versus water. The overall water balance of a wetland, therefore, has profound biogeochemical consequences. Other factors, including soil texture, compressibility, porosity, and buoyancy, also have an important influence on saturation. Bubbling, which represents an alternative mode of gas and vapour export, is also partially controlled by soil physics.

Secondly, the bulk flow of water represents a major route for import or export of biogeochemicals. Water flow is controlled in part by factors external to a wetland, including the hydraulic head and conductivity of adjoining ecosystems, and by meteorological variables. It is also controlled by soil characteristics such as hydraulic conductivity, pore size and compressibility, and vegetation. While rapid subsurface flow may occur in parts of some wetlands, rather low subsurface flow velocities are common in others.

The characterization of wetland hydrology and its ties to movement of biogeochemicals depends on the ability to measure both hydrologic fluxes and chemical gradients in a wetland. Several promising techniques are available or under development; these include better ways of accurately monitoring pore water pressures, and techniques for either chemical sampling or *in situ* chemical measurement.

GEOCHEMISTRY OF PEAT AND WATER TABLE OF PEATLANDS IN WEST-CENTRAL CANADA.

S.C. Zoltai, Forestry Canada, Northern Forestry Centre, Edmonton, Alberta T6H 3S5

Bogs and fens have been studied at 238 locations in the boreal regions of Alberta, Saskatchewan and Manitoba. Peat samples were taken at 15-cm intervals at each location and from the underlying mineral soil. Water was sampled from the water table. The elemental composition (Ca, Mg, Na, K, Al, Ti, Pb, Cu, Fe, Mn, Zn, Ni, S, P) of all peat, soil and water samples was determined with an ICP-AES.

The elemental composition of peat is influenced by a number of factors, including the availability, solubility and retention of various elements in the peatland environment. The elements available to the peatland plants originate by atmospheric depcsition (rain, mist, dust) and from groundwater. Bogs are fed entirely by atmospheric deposition (ombrotrophic), and fens are fed by groundwater that passed over or through mineral soil (minerotrophic). Some fens are located in small basins, but others receive water from a large watershed. The source of elements from the soils and bedrock in small basins is usually more uniform than in large, more diverse watersheds.

The solubility of the various elements is indicated by the relative amounts of the elements in the water as compared to the soil. Some elements, such as Na, Ni and S, are always present in higher amounts in the water than their concentration in the soil would suggest. On the other hand, Al, Ti, Fe and P are present in lower amounts in the water than expected. Others (K, Pb, Cu) tend to have lower than expected concentrations in the water of bogs and poor fens, but higher than expected concentrations in richer fens. The remainder (Ca, Mg, Zn and Mn) appear to be present in the water at amounts proportional to their levels in the soil.

A somewhat different picture emerges from the comparison of the elemental levels in the peat and in the soil. Sodium and Ni, although present in relatively high proportions in the water, are generally found at similar levels in the peat and in the soil. On the other hand, S is invariably more prevalent in the peat than in the soil. Calcium is generally more concentrated in the peat, especially in the minerotrophic peatlands, but Mg can be either more or less concentrated in the soil. Aluminum, Ti, and Fe are less abundant in the peat than in the soil, in accordance with their lower solubility. On the other hand, P is always more abundant in the peat than in the soil.

In addition to these general relationships, other consistent trends have been detected. Potassium and Mn are always far more concentrated in the tissues of living and recently dead vegetation than in the main body of the peat deposit. Sulfur, on the other hand, tends to increase in concentration with the depth of the deposit. Impurities, either from natural (volcanic ash) or anthropogenic causes (pollution, road dust, etc.) can cause sharp, anomalous peaks of certain elements.

The conventional classification of peatlands as poor to rich is related to elements that influence the alkalinity of the peatland, dominantly Ca and Mg. Gradients in these elements can be correlated with pH and conductivity, which in turn have been found to have dominant influence on the vegetation. Although the Ca and Mg gradients do not necessarily reflect similar gradients in other elements, this classification is acceptable for the study of peatland ecology.

EXTENDED ABSTRACT
"HUMIC LAKE ACIDIFICATION EXPERIMENT (HUMEX)"

by Egil T. Gjessing, Oslo, Norway.

Early in the 1960's it was suggested, for the first time, that acid rain and surface water acidification could explain the observed reduction in fish catch in major salmon rivers in Southern Norway. In 1972 an extensive research program in Norway was started. It had the aim of studying the effect of acid rain on forests and freshwater. The SNSF-Project, "Acid Rain, Effect on Forestry and Fish," ran for 8 years, and was finished in 1980. Most of the research focused on clear water lakes and rivers.

In some parts of Norway the surface waters are coloured with a high content of humic substances. Both the chemical and the biological effects of acid rain are different in this type of water.

Humic substances are very complicated dissolved organic matter that originates from soil. These organics play an important role in water pollution in general by altering the biological effect of most pollutants.

The HUMEX project was launched in 1988 by NIVA to investigate the role of humic substances in the acidification of surface water, and the role that acidification plays in the chemical and biological properties of the humic substances. In the HUMEX project, "Humic Lake Acidification Experiment", a whole catchment, including a humus rich lake, will be artificially acidified.

An important condition for this project is that the experimental area be located in a region which receives little or no acid precipitation. The site for this experiment is a dystrophic lake east of Førde in the water course of Jølster. It met all of the various practical and scientific conditions.

Lake Skjervatjern is 2,4 hectares in area, with a total catchment area of 10.4 hectares. This area has been rented for a period of 5 years. A proper reference was achieved by dividing lake Skjervatjern into two separate basins using a plastic curtain, from the middle of the natural outlet to the opposite shore. In order to do this, a 100 meter plastic-curtain was needed. The maximum depth of the lake here was 4,5 meters. The plastic curtain which is, of course, watertight is guaranteed to last for at least 5 years. The curtain, which has a density slightly above 1, is kept floating by styrol foam collar and is pressed into the mud by a great number of bags filled with sand.

There are now two separate basins with two separate outlets. One half of the lake and the corresponding catchment will be treated with artificially acidified precipitation. Before starting this acidification it was important to know as much as possible about chemical and biological

differences and similarities in the two basins. For two years, from autumn 1988 to autumn 1990, the chemistry of the two outlets has been monitored, and through the two last summers, ecologists, limnologists, biologists and soil scientists have collected reference data from the lake and its catchment. Researchers from several institutes both from Norway and abroad participate.

The acidification is carried out by about 50 sprinkling devices, each mounted at the top of the highest trees. The water used for this artificial acidification is taken from a nearby lake. This water is very low in salts and organic carbon. After the addition of sulphuric acid the water is pumped via a distribution device to the various parts of the catchment. There is need for a considerable volume of water for a proper treatment, and as the differences in elevation are also considerable, advanced technical installations are required. Several hundred meters of high-pressure plastic tubes distribute the water to the sprinklers.

Both the technical installations and the expected research activities require laboratory, storage, and living facilities. These are located by the lake, from where the water used for acidification is taken.

The HUMEX-project will provide direct experimental evidence leading to a better understanding of the biological effects of acidification. The project has received international attention; so far a dozen Norwegian scientists and a similar number from abroad are participating in the project.

As this project is the first of its kind in the world, the first results are eagerly awaited.

Wetlands and Sensitivity of Terrestrial Carbon Cycle on Atmospheric Carbon Dioxide

James R. Kramer*, Pierre Brassard*, Gilles Patry#, Imre Takacs#, McMaster University, Department of Geology*, Department of Civil Engineering#, Hamilton, Ontario, Canada L8S 4M1.

Inorganic geochemical models have been proposed recently for carbon cycling (for example, **1**). None of these models have included a mechanistic development of the biological aspects of carbon. Presumably carbon uptake and release in biological systems is very fast and is balanced. Therefore the portion of the system will not be important on long time scales in terms of carbon sinks or sources. These inorganic models are very "stiff" (**2**); they can not be back integrated, and they are negligibly affected by perturbations.

A first attempt at a terrestrial production model has been completed (**3**). Figure 1 shows a schematic of this model. In Figure 1, NPP is the net primary productivity and depends upon atmospheric CO_2 and the minimum of temperature and precipitation functions. Dw is the degradation rate of phytomass to metastable carbon ("humic substances") and depends upon the minimum of {temperature, precipitation}. Fpc is the degradation rate of plant material, Fr is the sedimentary organic carbon formation rate from root material. Fh1 and Fh2 are the formation rates of different sedimentary organic carbon, and Fc1, Fc2 etc. are the degradation rate of sedimentary organic carbon. It has been tuned to an average temperate mature forest. We used the Liebig limiting principle for precipitation (P_p) and temperature (t) dependence as formulated by Leith and Esser (**4**). Various scenarios have been used for formation and degradation of organic carbon (**4, 5, 6**). The purpose of this modelling exercise was to ascertain 1) the sensitivity of atmospheric CO_2 to the terrestrial biosphere, and 2) to ascertain the time to steady state when a major perturbation (0.5 times and 2 times atmospheric CO_2) was invoked. We looked at an average terrestrial biosphere for different assumed average precipitation scenarios, and we did not consider any interactions with the oceans.

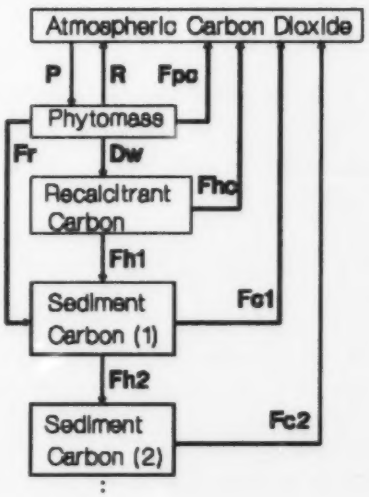

Figure 1. Schematic of model.

We made some interesting and important conclusions:

- "Terrestrial Gaia does exist!" The terrestrial system regulates atmospheric CO_2 well.

- Average precipitation level is very sensitive to results.
- The time to steady state is between 100-200 years.
- The most sensitive aspect of the model is the structure of the organic carbon compartments and their degradation rate. The literature values give reasonable values, but small changes in reaction kinetics increase or decrease the atmospheric CO_2 dramatically.

We have made some specific research recommendations from these findings. The organic carbon compartment (humus, recalcitrant carbon, sediment carbon) needs to be understood much better as mechanisms and dynamics. Secondly, the other important terrestrial ecosystems need to be evaluated and not merely "averaged" into the model.

The number of soil carbon compartments is not known well. There may be discrete compartments that can be related to soil position or mechanism, or there may be a continuum of reactions and their kinetics (**7**).

Wetlands play an important part in the terrestrial carbon dynamics and cycling. First of all, the net primary production in wetlands tends to be very high, and overall the total fixation of carbon is on a scale similar to that of temperate forests (**8**). Thus small changes in their small areas will have a pronounced effect on carbon uptake. Unfortunately there does not seem to be too much quantitative information on the mechanisms or dynamics of carbon in wetlands. Qualitatively sediment organic carbon in wetlands seems to be more stable than in drained areas, suggesting that organic carbon is cycled more rapidly under oxidizing conditions.

Primary production in wetlands is strongly affected by the hydrological regime (e.g. **9**). Indirectly then, the precipitation regime will be important to wetlands dynamics. On the other hand, nutrient limitation to primary production does not seem as sensitive as for temperate forests etc.

It is necessary to obtain a better idea of the sub-compartments and dynamics of carbon in a wetland's environment in order to add this most important part of the terrestrial carbon cycle to the global picture.

References:

1. Lasaga, A.C.; R.A. Berner; R.M. Garrels. "An Improved Geochemical Model of Atmospheric CO_2 Fluctuations over the past 100 Million Years", in E.T. Sundquist and W.S. Broecker (eds), The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present. Geophysical Monograph 32, Amer. Geophys. U. 397-411 (1985).

2. Kasting, J. "Comments on 'The Carbonate-Silicate Geochemical Cycle and its Effect on Atmospheric Carbon Dioxide over the past 100 million years'", Amer. J. Sci., 284:1175-1182 (1984).

3. Kramer, J.R.; P. Brassard, P.; G. Patry; I. Takacs. "Sensitivity of Terrestrial Carbon Cycle on Atmospheric Carbon Dioxide", Chem. Geol., 84:166-168 (1990).

4. Esser, G. "The Significance of Biospheric Carbon Pools and Fluxes for the Atmospheric CO_2: a Proposed Model Structure", in H. Leith, R. Fantechi and H. Schnitzler (eds), Interactions Between Climate and Biosphere, Swets and Zeitlinger B.V., Lisse, 253-294 (1984).

5. Sundquist, E.T. "Geological Perspectives on Carbon Dioxide and the Carbon Cycle", in (E.T. Sundquist and W.S. Broecker, eds), The Carbon Cycle and Atmospheric CO_2; Natural Variations Archean to Present, Geophys. Monogr. 32, Amer. Geophys. Un., Washington, D.C., 5-61 (1985).

6. Goudriaan, J; P. Ketner. "Are Land Biota a Source or a Sink for CO_2?", in H. Leith, R. Fantechi and H. Schnitzler (eds), Interactions Between Climate and Biosphere, Swets and Zeitlinger B.V., Lisse, 247-252 (1984).

7. Middleburg, J.J. "A Simple Rate Model for Organic Mater Decomposition in Marine Sediments", Geochim. et Cosmochim. Acta, 53:1577-1581 (1989).

METHANE EMISSIONS FROM PEATLANDS

T.R. Moore
Department of Geography
McGill University
Montreal

Atmospheric concentrations of methane are increasing at a rate of about 1 % y^{-1}, with an estimated total global emission rate of about 500 Tg y^{-1} [5]. A radiatively and chemically active gas, methane, is believed to account for about 12 % of the proposed global warming associated with changes in atmospheric chemistry [7].

A major natural source of methane emissions to the atmosphere is waterlogged soils, such as rice paddies and wetlands. Recent estimates of the importance of the wetland source range from 40 to 160 Tg CH_4 y^{-1} [1, 10]. Of the global area of wetlands of about 5.7 x 10^6 km^2, about 55 % fall in northern latitude temperate to subarctic regions. Combined with the largest concentration of atmospheric methane in the high latitudes of the northern hemisphere, it has been suggested that northern wetlands may be major global source of methane.

Although tower and aircraft measurements of methane flux from wetlands have been used in a few cases, most data on methane emissions have been derived from static or dynamic chambers, in which changes in atmospheric concentration of methane can be used to calculate the flux. Although creating an artificial environment within the chamber, it appears that there is general concordance of measurements from chambers and towers, though circulating air inside the chamber increases flux rates by about 20 % [15, 21]. Chambers can cover many habitats within a wetland, but there is high spatial variability in methane flux measurements from replicate chambers within apparently uniform sites. Coefficients of variation within sites with little ecological diversity are commonly in the range of 0.2 to 0.6, with standard error/mean ratios of 0.10 being achieved with about 15 chambers per site [2, 15]. Where there is large ecological diversity within a site, coefficients of variation frequently exceed 1.0. Methane fluxes can vary by an order of magnitude over short distances, such as string-pool systems in subarctic fens [13].

Methane flux from a soil represents the balance between methanogens and methanotrophs and the ability of the soil to transmit methane upwards, either through diffusion, through bubbling or through plants, such as water lily [6]. Major controls on methane emissions from wetlands fall into 3 types: thermal regime; hydrologic regime; and plant and edaphic characteristics.

Thermal regime exerts a control through its influence on microbiological activities; although Q_{10} values for methane production in the laboratory are commonly in the range 2 - 4 [23], strong relationships are not commonly observed in field situations, where large spatial variability in flux measurements, changes in water table position and vegetation and lag between thermal regime and flux obscure the relationship [14].

Hydrologic regime exerts an influence through the creation of anaerobic conditions beneath and aerobic conditions above the water table, fostering methane production and consumption, respectively. Laboratory studies have been able to identify the nature of the water table:flux relationship [13], though in field studies, the relationship is often clouded by changes in other variables within sites [16]. Collation of literature on water table and methane flux reveals the overall importance of this variable (Bubier, pers. comm.).

Seasonal variations in methane flux often follow variations in thermal and hydrologic regime. Southern swamps emit methane during the spring and fall when saturated, but emission rates decrease, or the swamp becomes a sink for methane, when the water table drops during the summer [9, 14]. Subarctic fens show a strong increase in emission rates with summer warming, especially at sites in which the fen surface floats, thereby keeping the surface saturated [16, 18]. Episodic methane fluxes have also been observed, during the spring thaw and summer water table draw-down of subarctic fens, the freezing of tundra soils and after heavy rainfall events [16, 27]. Storage of methane in pore water may equal in the annual methane flux in subarctic fens [16].

Plants also play a role in determining methane emissions, either passively in reflecting the habitat requirements of methanogens and methanotrophs or actively through either venting to the atmosphere, or by rhizosphere oxidation of methane. Edaphic controls on substrate availability are poorly understood.

The large spatial and seasonal variability of methane emissions, combined with its episodic nature, hinder the reliable estimation of annual methane fluxes from wetlands. Measurements made as part of the Northern Wetland Study at Churchill, Moosonee and Schefferville suggest that annual methane fluxes fall in the ranges:

<u>Sphagnum</u> bogs < 0.1 g CH_4 m^{-2} y^{-1}
Fens 1 - 15 g CH_4 m^{-2} y^{-1}
Strings 1 - 3 g CH_4 m^{-2} y^{-1}
Pools and degrading peatlands 5 - 15 g CH_4 m^{-2} y^{-1}
Coastal marshes and pools 5 - 10 g CH_4 m^{-2} y^{-1} (from [10, 12, 14, 15, 17])

Although significant amounts of methane are emitted from aggrading peatlands and floating subarctic fens, maximum methane emissions are recorded from sites in which the peat is degrading.

Data collected from other peatlands in Canada suggest high fluxes (> 10 g CH_4 m^{-2} y^{-1}) in minerotrophic fens, Alberta [4], low to moderately high values for beaver ponds [6, 19, 24], low to moderate values for swamps [14] and very low values (< 1 g m^{-2} y^{-1}) for bogs [3, 4, 13].

Inclusion of these measurements from diverse wetland types into global extrapolations suggests that northern wetlands, such as those found in Canada, may not be such an important source of methane as originally estimated. Canadian wetlands probably contribute no more than 5 - 10 Tg y^{-1}.

The question of how wetland methane emissions will respond to climate change scenarios can be answered in two ways. One is the analogue approach, in comparing fluxes at the same site over years with different rainfall and temperature. Measurements over 2 or more years at the same sites are rare, but suggest that variations in water table, associated with abnormally dry or wet years can produce flux reductions of 50 to 85 % [dry:average years, Churchill [10]] to increases of 350 to 170 % [wet:average years, Schefferville [14]].

Alternatively, predictions of changes in temperature and precipitation associated with 2 x CO_2 climate models can be used to generate hydrologic and thermal regime models. One can then compare increased methane flux associated with higher temperatures with decreases predicted to occur from drops in the water table caused by higher evapotranspiration rates. For subarctic fens near Schefferville, Roulet et al. [20] have predicted that 2 x CO_2 changes in temperature and rainfall will result in decreased summer emission of methane of between 68 and 100 % for a floating and non-floating fen, respectively.

References

1. Aselmann, I. and P.J. Crutzen, 1989. Global distribution of natural freshwater wetlands and rice paddies, their net primary productivity, seasonality and possible methane emissions. J. Atmos. Chem. 8: 307-359.

2. Bartlett, D.S., K.B. Bartlett, J.M. Hartman, R.C. Harriss, D.I. Sebacher, R. Pelletier-Travis, D.D. Dow and D.P Brannon, 1989. Methane emissions from the Florida Everglades: patterns of variability in a regional wetland ecosystem. Global Biogeochem. Cycles 4: 315-336.

3. Bartsch, I and T.R. Moore, unpub. data. Methane emissions from 4 peatlands, central Maine.

4. Bayley, S., unpub. data. Methane emissions from bogs and fens.

5. Cicerone, R.J and R.S. Oremland, 1988. Biogeochemical aspects of atmospheric methane. Global Biogeochem. Cycles 2: 299-327.

6. Dacey, J.W.H. and M.J. Klug, 1979. Methane efflux from lake sediments through water lilies. Science 203: 1253-1255.

7. Ford, T.E. and R.J. Naiman, 1988. Alteration of carbon cycling by beaver: methane evasion rates from boreal forest streams and rivers. Can. J. Zoology 66: 529-533.

8. Hansen, J., A. Lacis and M. Prather, 1989. Greenhouse effect of chlorofluorocarbons and other trace gases. J. Geophys. Res. 94 (D13): 16417-16421.

9. Harriss, R.C., D.I. Sebacher and F.P. Day, 1982. Methane flux from the Great Dismal Swamp. Nature 297: 673-674.

[10]. Holland, S., W.R. Rouse and T.R. Moore, unpub. data. Methane emissions from wetlands in the Churchill area.

[11]. Matthews, E. and I. Fung, 1987. Methane emissions from natural wetlands: global distribution, area and environmental characteristics of sources. Global Biogeochem. Cycles 1: 61-86.

[12]. Moore, T.R., A. Heyes and N.T. Roulet, unpub. data. Methane emissions from wetlands in the Moosonee area.

[13]. Moore, T.R. and R. Knowles, 1989. The influence of water table levels on methane and carbon dioxide emissions from peatland soils. Can. J. Soil Sci. 67: 77-81.

[14]. Moore, T.R. and R. Knowles, 1990. Methane emissions from fen, bog and swamp peatlands in Quebec. Biogeochemistry 11: 45-61.

[15]. Moore, T.R. and N.T. Roulet, 1991. A comparison of dynamic and static chambers for the measurement of methane flux from subarctic fens. Atmosphere-Ocean 29: 16-23.

[16]. Moore, T.R., N.T. Roulet and R. Knowles, 1990. Spatial and temporal variations of methane flux from subarctic/northern boreal fens. Global Biogeochem. Cycles 4: 29-46.

[17]. Moore, T.R. and J. Windsor, unpub. data. Methane emissions from wetlands in the Schefferville area.

[18]. Sebacher, D.I., R.C. Harriss and K.B. Bartlett, 1983. Methane flux across the air-water interface: air velocity effects. Tellus 35B: 103-109.

[19]. Roulet, N.T., in press. Surface adjustment in northern peatlands: the maintenance of effective surface saturation. Arctic Alpine Res.

[20]. Roulet, N.T., unpub. data. Methane emissions from wetlands in the Dorset area.

[21]. Roulet, N.T., T.R. Moore and P. Lafleur, unpub. ms. Northern fens, methane flux and climatic change.

[22]. Whalen, S.C. and W.S. Reeburgh, 1988. A methane flux time series for tundra environments. Global Biogeochem. Cycles 2: 399-409.

[23]. Williams, R.T. and R.L. Crawford, 1984. Methane production in Minnesota peatlands. Appl. Environ. Microbiol. 47: 1266-1271.

[24]. Yavitt, J.B., G.E. Lang and A.J. Sexstone, 1990. Methane fluxes in wetland and forest soils, beaver ponds, and low-order streams of a temperate forest ecosystem. J. Geophys. Res. 95 (D13): 22463-22474.

SUGGESTIONS AS TO WETLAND RESEARCH NEEDS

Eville Gorham

A. Present system states -- along gradients within and among wetlands

1. Physical -- hydrology (water-table, hydraulic head, streamflows, amount of open water)
   -- permafrost distribution and thickness
   -- seasonal temperature profiles down to stable conditions.

2. Chemical -- dissolved components in pools and outflow streams: pH, Ca, DOC, N_{tot}, P_{tot}, S_{tot} elements by ICP spectrometry: Ca, Mg, Na, K, Fe, Mn, Al, etc.
   -- volatile emissions: CO_2, CH_4, and possibly volatile compounds of N and S.

3. Biological -- inventory of flora and fauna in relevé plots and along transects from edge to lowest point of many diverse wetlands
   -- lists of rare, threatened and endangered species
   -- measurements of productivity, decomposition and storage in sites selected for long-term monitoring
   -- studies of tree-rings as a measure of forest productivity (related also to hydrological and climatic fluctuations)

B. Past system states -- in at least those sites chosen for long-term monitoring

1. Rates of accumulation of organic matter, C, N, S, P, etc., in peat cores dated by radio-isotopic and other techniques.

2. Lateral spread of large peatlands in major peat-covered regions, measured by dating basal peats with ^{14}C.

3. Shifting of peatland boundaries (north and south) over the postglacial period, measured as above.

4. Changes in peatland typology (bog, fen, reedswamp, marsh) over time and space, by study of dated peat cores.

5. Alterations in peatland patterns within large peatland complexes.

6. Reconstruction, in at least those sites chosen for long-term monitoring, of the paleorecord of (1) acidity and (2) height of the peat surface above mean water-table by means of multivariate statistics applied to the stratigraphy of bryophytes, and perhaps

testate amoebae. Other fossils should allow reconstruction of salinity profiles in prairie wetlands.

7. Reconstruction, in wooded sites, of the recent paleorecord of hydrology, by interpretation of tree-ring widths.

8. Investigation, using techniques pioneered by Margaret Davis for tree species, of the rates of migration of dominant peatland plants.

C. Future system states

1. Long-term monitoring of selected boreal peatlands and prairie wetlands (see A above) with special attention to the effects of climatic warming upon (a) amount of open water, (b) depth of watertable, (c) streamflow and chemical exports from the site, (d) depth of permafrost, (e) gaseous emissions, (f) biotic composition and diversity with special attention to threatened and endangered species, and (g) tree growth.

2. Alterations in the northern and southern boundaries of active peat accumulation.

3. Alterations in the distribution of permafrost, thermokarst erosion, open water (especially thaw lakes), etc.

4. Alterations in the numbers and types of prairie "pothole" wetlands, with special attention to their migration eastward onto dried-out lake basins. Wildfowl populations might receive special attention.

5. Modelling and model predictions.

D. Experimental approaches

1. Investigation of the influence of water-table alteration upon present system states, with particular attention to gaseous emissions and stream exports. (Examination of peatlands drained but not otherwise altered might be useful here).

2. Investigation of the effects of permafrost melting upon present system states, with particular attention to gaseous emissions and stream exports.

3. Investigation of the influence of acid deposition upon present system states in circumneutral, poor-fen sedge meadows transitional to acid Sphagnum bogs, using techniques pioneered by Suzanne Bayley.

E. Geographic focus

1. Wetlands and peatlands across major boundaries (e.g., permafrost, tree-line, prairie/forest border).

2. Large peatland complexes, especially in the Hudson/James Bay Lowland.

3. Prairie "pothole" wetlands.

4. Coastal wetlands, including blanket bogs in the Avalon peninsula of Newfoundland.